THE

GEOLOGICAL MAGAZINE

NEW SERIES. DECADE VI. VOL. III.

No. VII.—JULY, 1916.

ORIGINAL ARTICLES.

I.—Eminent Living Geologists.

John Edward Marr, Sc.D. (Camb.), F.R.S., F.G.S., Fellow and Lecturer of St. John's College, Cambridge, and University Lecturer in Geology.

(WITH A PORTRAIT, PLATE XI.)

THE subject of the present memoir occupies a distinguished position as lecturer and teacher of our science in the University of Cambridge, one which he has held for more than thirty years, and he is well known among geologists generally as a high authority on the Palæozoic rocks, his writings being recorded in the "Quarterly Journal" of the Geological Society (of which Society he has filled the offices both of Secretary and President). His name has also frequently appeared as the author of important papers in the Geological Magazine and other works.

John Edward Marr, the third son of John and Mary Marr, was born at Morecambe, Lancashire, June 14, 1857; he was educated at the Lancaster Grammar School, already famous as having been the nursery of two eminent scientific men, Dr. Wm. Whewell, F.R.S., Master of Trinity, and Professor Sir Richard Owen, K.C.B., F.R.S., Hunterian Professor at the Royal College of Surgeons and afterwards head of the Natural History Departments in the British Museum.

For some years before entering Cambridge, Marr lived at Carnarvon, where his interest in geology was aroused among the rocks of Snowdonia, and when at school he had the advantage of geological teaching from the Rev. Thomas Adams, M.A., and practical work in the field under Mr. R. H. Tiddeman, M.A., F.G.S., who was then surveying the Lancaster district.

In 1875 J. E. Marr entered St. John's College, Cambridge, with an Exhibition, and had the benefit of studying under Professor McKenny Hughes and the Rev. T. G. Bonney, in the lecture-room, museum, and field. By his application Marr obtained a Foundation Scholarship, and graduated First Class in the Natural Science Tripos in 1878.

The year following he spent some weeks in a careful study of the Lower Palæozoic rocks of Bohemia and critically examined Barrande's so-called 'colonies', of which that accomplished geologist had published so much. The writer recalls the humorous remark of Professor Huxley at a Council meeting of the Geological Society, that now Marr had upset Barrande's interpretation of these isolated

masses he should, alas! receive no more pamphlets from Prague on the "Defense du Colonies", which were so entertaining.

In 1880 Marr spent a considerable time in visiting the historical localities of the Lower Palæozoic rocks of Scandinavia. Both these expeditions were aided by grants from the Worts Travelling Fund of the University. The results of his investigations were presented in papers read before the Geological Society and printed in the Quarterly Journal and the GEOLOGICAL MAGAZINE (1881, p. 245; 1882, p. 282; 1883, p. 263, etc.).

During this period Marr had the advantage of much useful training in lecture-work while acting as Lecturer to the University Extension Scheme, and for one winter of that period he served the office of Deputy to Professor A. H. Green at Leeds.

J. E. Marr was elected a Fellow of St. John's College, Cambridge, in 1881, and appointed University Lecturer in Geology in 1886, having been informally engaged in teaching in the University some years previously. Shortly after his appointment he was also made College Lecturer in Geology.

Since 1886 Dr. Marr has devoted himself mainly to teaching in Cambridge and to geological research. His studies in the field were largely in the complex Palæozoic rocks of the Lake District, but embraced other home areas, as well as on the Continent. He has done much work as an Examiner at Cambridge and other Universities and has served on many Boards and Syndicates in the University, and has been elected to the Councils of the Royal Society, the British Association, and the Geological Society. He entered the Council of the last-named Society in 1885, and has since served almost continuously, save for five years in a period of thirty-one, filling the office of Secretary for ten years, Vice-President during sixteen years, and as President for two years.

In carrying out field-work he has been fortunate in his colleagues, including, among others, Thomas Roberts, Alfred Harker, Henry Alleyne Nicholson, and E. J. Garwood. One of the heavy blows in his life was the loss of Nicholson at a time when his friends all hoped that he had many years of good work before him.

Dr. Marr writes: "The geologist goes into the field not only as a researcher, but ever as a student, and in these later years I gratefully recall the instruction I have received from Professor Charles Lapworth, at whose feet so many geologists have sat." He also acknowledges to have received much assistance from many of his pupils while carrying on field observations. He was being helped in the Lake District by his son (now Captain Alleyne Marr) when the War broke out; Captain Marr is now serving at the Front.

Owing to the almost continuous service of Dr. Marr as a Member of Council, it was difficult to find an occasion when that body could vote one of its medals to a Fellow who, by his long-continued services, had done so much to aid the science of geology and the interests of the Society. It came in 1900, when he was awarded the Lyell Medal, and the President referred to his numerous contributions to the Society's Journal and to the GEOLOGICAL MAGAZINE (from 1876 onwards) on the Lake District and its borders,

on Wales, and on the pre-Devonian rocks of Bohemia. He also specially referred to those on the Stockdale Shales (in conjunction with the late Professor Nicholson), on the Shap Granite and its associated rocks with Dr. Alfred Harker, F.R.S. (the present President), and on limestone knolls. Mr. Whitaker also cited other works by Dr. Marr on *The Cambrian and Silurian Rocks*, *The Principles of Stratigraphical Geology*, and *The Scientific Study of Scenery*.

Fourteen years later (in 1914) the Council awarded the blue ribbon of the Geological Society, the Wollaston Medal, to Dr. Marr, and the President, Dr. Aubrey Strahan, referred to his brilliant University career and the continuity of his labours since 1880 in the task of assisting the Woodwardian Professor to create in Cambridge the foremost school of geology in Britain. He described Dr. Marr's investigations in the field on the Lower Palæozoic rocks and on the zoning of the strata between the Coniston Limestone and the Coniston Grits in the Lake District, on the continuation of those researches into North Wales, and the comparison of the sequence, as there developed, with that of the Lake District. He referred to Marr's visit to Bohemia and his investigation of the boundary between the Cambrian and Silurian, and his careful comparisons of the Bohemian and British developments, incidentally to show that there existed serious objections to the acceptance of Barrande's colonies, both on palæontological and stratigraphical grounds.

No sketch of his life-labours in Cambridge would be complete if we failed to pay a tribute to the able way in which Dr. Marr's teaching work has been aided and encouraged by his wife. One of his old students writes: "Marr's profound knowledge of his subject, his youthful enthusiasm, and his sympathy with the undergraduate have all contributed to make him the most successful of teachers. It has always been his endeavour to get into closer touch with his pupils than could well be done in the lecture-room, and in this he has been aided in no small measure by his wife. Every Sunday afternoon and evening during term-time students were welcomed at their house, a privilege and a kindness that meant much to the undergraduate, who sees all too little of home-life while at the University. Neither Marr nor Mrs. Marr lose sight of a student when he leaves Cambridge, for by that time he has passed from the status of pupil to that of personal friend, and his advance in the geological world is aided and watched with pleasure."

The following are the principal dates relating to Dr. Marr's career: B.A. 1879; M.A. 1882; Sc.D. 1904; F.G.S. 1879; F.R.S. 1891; Sec. G.S. 1888–98; V.P.G.S. 1901–3, 1906–8, 1911–13; Pres. G.S. 1904–6; Lyell Medallist 1900; Wollaston Medallist 1914.

Dr. Marr received Hon. Ph.D. in the Bohemian University of Prague in 1908; President Section C (Geology) British Association 1896; delivered lecture to Operative Classes at Cambridge Meeting of British Association 1904; delivered Tyndall Lecture at Royal Institution 1906.

He is an Honorary Member of the Geologists Association and of other British Scientific Societies; also of the Geological Society of Belgium, and the Natural History Society of New Brunswick.

Dr. Marr is the author of the following publications:—

1876. "Note on the Occurrence of Phosphatised Carbonate of Lime at Cave Ha, Yorkshire": GEOL. MAG., Dec. II, Vol. III, pp. 268–9.
"Fossiliferous Cambrian Shales near Caernarvon": Quart. Journ. Geol. Soc., vol. xxxii, pp. 134–5; Phil. Mag., ser. v, vol. i, p. 329.

1878. "On some well-defined Life-zones in the lower part of the Silurian (Sedgw.) of the Lake District": Quart. Journ. Geol. Soc., vol. xxxiv, pp. 871–85.

1880. "Note on the Phacopidæ of the Lake District": Proc. Camb. Phil. Soc., vol. iii, pp. 68–9.
"On the Cambrian (Sedgw.) and Silurian Beds of the Dee Valley, as compared with those of the Lake District" (1879): Quart. Journ. Geol. Soc., vol. xxxvi, pp. 277–84.
"On the Predevonian Rocks of Bohemia": Quart. Journ. Geol. Soc., vol. xxxvi, pp. 591–618.

1881. "Syllabus of a Course of Lectures on Geology": Cambridge University Local Lectures, pp. 31.
"On some Sections in the Lower Palæozoic Rocks of the Craven District": Proc. Yorks Geol. Soc., vol. vii (1878–81), pp. 397–9.
"The Classification of the Cambrian and Silurian Rocks": GEOL. MAG., Dec. II, Vol. VIII, pp. 245–50.

1882. *The Classification of the Cambrian and Silurian Rocks.* Being the Sedgwick Prize Essay for 1882, pp. xxiv, 147.
"On the Cambrian (Sedgw.) and Silurian Rocks of Scandinavia": Quart. Journ. Geol. Soc., vol. xxxviii, pp. 313–27.

1883. "Origin of the Archæan Rocks": GEOL. MAG., Dec. II, Vol. X, pp. 263–73.

1885. (With T. ROBERTS) "The Lower Palæozoic Rocks of the Neighbourhood of Haverfordwest": Quart. Journ. Geol. Soc., vol. xli, pp. 476–91, 1 map.

1887. "The Lower Palæozoic Rocks near Settle": GEOL. MAG., Dec. III, Vol. IV, pp. 35–8.
"On the Lower Palæozoic Rocks of Settle": Rep. Brit. Assoc., 1886, pp. 663–4.
"The Work of Ice Sheets": GEOL. MAG., Dec. III, Vol. IV, pp. 151–5.
"The Glacial Deposits of Sudbury, Suffolk": GEOL. MAG., Dec. III, Vol. IV, pp. 430–1.
"On *Homotaxis*": Proc. Camb. Phil. Soc., vol. vi, pp. 74–82.

1888. "Some Effects of Pressure on the Sedimentary Rocks of North Devon": Rep. Brit. Assoc., 1887, p. 706; GEOL. MAG., Dec. III, Vol. V, pp. 218–21.
(With H. A. NICHOLSON) "The Stockdale Shales": Quart. Journ. Geol. Soc., vol. xliv, pp. 654–734.

1889. "On the Superimposed Drainage of the English Lake District": GEOL. MAG., Dec. III, Vol. VI, pp. 150–4.
"Notes on the Lower Palæozoic Rocks of the Fichtelgebirge, Frankenwald, and Thuringerwald": GEOL. MAG., Dec. III, Vol. VI, pp. 411–15.

1890. "Dynamic Metamorphism of Skiddaw Slates": Rep. Brit. Assoc., 1889, p. 568.
"The Connection betwixt Yorkshire and Scandinavia": The Naturalist, 1890, p. 145.

1891. "The Backbone of England": Trans. Leeds Geol. Assoc., pt. vi, p. 51.
"Pre-Cambrian, Cambrian, and Silurian": Report of British Committee on Classification and Nomenclature; Compte Rendu Congrès Geol. Intern. (1888), pp. B 161–78.
(With ALFRED HARKER) "The Shap Granite, and the Associated Igneous and Metamorphic Rocks": Quart. Journ. Geol. Soc., vol. xlvii, pp. 266–328.
(With H. A. NICHOLSON) "Cross Fell Inlier": Quart. Journ. Geol. Soc., vol. xlvii, pp. 500–12, pl. xvii.

(With R. H. TIDDEMAN) "The Geology of West Yorkshire": Compte Rendu Congrès Geol. Intern. (1888), p. 303.

(With H. WOODWARD, R. ETHERIDGE, and G. F. WHIDBORNE) "The best methods for the Registration of all Type Specimens of Fossils in the British Isles": 1st Rep. of Committee, Brit. Assoc. Rep., 1890, p. 339; 2nd Rep., 1891, pp. 299–300 (1892); 3rd Rep., 1892, p. 289 (1893); 4th Rep., 1893, p. 482 (1894).

"Geology of Appleby": Chapter v of a Guide-book to Appleby, by Canon Mathews, pp. 71–5.

1892. "On the Wenlock and Ludlow Strata of the Lake District": GEOL. MAG., Dec. III, Vol. IX, pp. 534–41.

"The Coniston Limestone Series": GEOL. MAG., Dec. III, Vol. IX, pp. 97–110.

"Further Remarks on the Coniston Limestone": GEOL. MAG., Dec. III, Vol. IX, pp. 443–7.

1893. (With ALFRED HARKER) "Supplementary Notes on the Metamorphic Rocks around the Shap Granite": Quart. Journ. Geol. Soc., vol. xlix, pp. 359–71, pl. xvii.

1894. "Physiographical Studies in Lakeland": GEOL. MAG., Dec. IV, Vol. I, pp. 489–539.

"Works on the Palæozoic Rocks, published in 1894": Sci. Progress, vol. ii, pp. 96–108.

(With T. LEIGHTON) "Excursion to Cambridge and Ely": Proc. Geol. Assoc., vol. xiii, pp. 292–5.

1895. "Foreign Work amongst the Older Rocks": Sci. Progress, vol. iii, pp. 10–22.

"Physiographical Studies in Lakeland": GEOL. MAG., Dec. IV, Vol. II, pp. 299–303.

"The Tarns of Lakeland": Quart. Journ. Geol. Soc., vol. li, pp. 35–48.

"The Study of the Ancient Sediments": Sci. Progress, vol. iv, pp. 1, 313–22.

(With E. J. GARWOOD) "Zonal Divisions of the Carboniferous System": GEOL. MAG., Dec. IV, Vol. II, pp. 550–2; Rep. Brit. Assoc., 1895, p. 696.

(With H. A. NICHOLSON) "Notes on the Phylogeny of the Graptolites": GEOL. MAG., Dec. IV, Vol. II, pp. 529–39.

"Forms of Mountains": Nat. Sci., vol. vi, pp. 240–3.

(With H. A. NICHOLSON) "Notes on the Phylogeny of the Graptolites": Rep. Brit. Assoc., 1895, p. 695.

1896. "Additional Notes on the Tarns of Lakeland": Quart. Journ. Geol. Soc., vol. lii, p. 12.

Address to the Geological Section of the British Association: Rep. Brit. Assoc., 1896, vol. lxvi, pp. 762–75; Nature, vol. liv, pp. 494–500; GEOL. MAG., Dec. IV, Vol. III, p. 464.

"The Graptolites": Sci. Progress, vol. v, pp. 360–73.

"On the Lake Basins of Lakeland": Proc. Geol. Assoc., vol. xiv, p. 273.

"The Lake Basins of Lakeland" (abstract): Glac. Mag., vol. iv, p. 21.

"The Waterways of English Lakeland" (map, 1 inch = 4 miles): Geog. Journ., vol. vii, pp. 602–25.

"Life-zones in the British Carboniferous Rocks": Report of the Committee appointed to study the Life-zones in the British Carboniferous Rocks. Rep. Brit. Assoc., 1895, p. 696; GEOL. MAG., Dec. IV, Vol. III, p. 519.

1897. "The Origin of Lakes": Sci. Progress, N.S., vol. i, pp. 218–28.

1898. *The Principles of Stratigraphical Geology* (Camb. Nat. Sci. Ser.), pp. 304, text-illust.

"The Development of British Scenery": Sci. Progress, vol. vii, pp. 275–86.

(With R. H. ADIE) "The Lakes of Snowdon": GEOL. MAG., Dec. IV, Vol. V, pp. 51–61.

1899. "Note on a Conglomerate near Malmerby [Cumberland]": Quart. Journ. Geol. Soc., vol. lv, pp. 11–13, fig.
"On Limestone-knolls in the Craven District of Yorkshire and elsewhere": Quart. Journ. Geol. Soc., vol. lv, pp. 327–8, pl. xxiv; Abs. Proc. Geol. Soc., 1898–9, pp. 88–9.

1900. *The Scientific Study of Scenery*, pp. ix, 368, text-illust.
"Notes on the Geology of the English Lake District": Proc. Geol. Assoc., vol. xvi, pp. 449–83.
"Long Excursion to Keswick" (with Supplementary Excursion to Causey Foot, Eycott Hill, and Threlkeld Mine, under the leadership of John Postlethwaite; photographs, pl. xiv, by A. K. Coomáraswámy): Proc. Geol. Assoc., vol. xvi, pp. 526–32, pls. xiii, xiv, map (Volcanic Rocks of the Lake District).

1901. "The Origin of Moels and their subsequent Dissection": Rep. Brit. Assoc., 1900, pp. 818–19; Geog. Journ., vol. xvii, pp. 63–9, figs.
["Origin of Coal"]: GEOL. MAG., Dec. IV, Vol. VIII, pp. 33–4.

1902. "Lakes of Snowdonia": GEOL. MAG., Dec. IV, Vol. IX, pp. 430, 527.

1903. *Agricultural Geology*, pp. xi, 318, figs., 1 pl. (geol. map of the British Isles).

1904. "The Geology of Cambridgeshire": GEOL. MAG., Dec. V, Vol. I, pp. 508–9.
"Geology of the Shap District": in Rev. J. Whiteside's *Shappe in Bygone Days*, pp. 253–72.
(With W. G. FEARNSIDES) *The Physiography of Cambridgeshire*: Handbook to Nat. Hist. Camb., ed. by J. E. Marr.
(With A. E. SHIPLEY, etc.) *Handbook to the Natural History of Cambridgeshire*, pp. viii, 260, 4 maps (1 geol.).

1905. Anniversary Address ("The Classification of the Sedimentary Rocks"): Abs. Proc. Geol. Soc., 1904–5, pp. 52–3; Quart. Journ. Geol. Soc., vol. lxi, pp. lxi–lxxxvi.
"The Geology of Cambridgeshire": Rep. Brit. Assoc., 1904, pp. 541–2.
An Introduction to Geology, pp. viii, 229, 3 pls., text-illust.

1906. Anniversary Address ("The Influence of the Geological Structure of English Lakeland upon its Present Features—A Study in Physiography"): Abs. Proc. Geol. Soc., 1905–6, pp. 59–60; Quart. Journ. Geol. Soc., vol. lxii, pp. lxvi–lxxvii, figs., 1 pl.
"On the Stratigraphical Relations of the Dufton Shales and Keisley Limestone of the Cross Fell Inlier": GEOL. MAG., Dec. V, Vol. III, pp. 481–7, figs. (geol. map).

1907. "On the Ashgillian Series": GEOL. MAG., Dec. V, Vol. III, pp. 59–69.
"The Geology of the Appleby District, Westmorland": Proc. Geol. Assoc., vol. xx, pp. 129–48, figs., pls. i and iii (geol. map), and pp. 193–9, fig., pls. vi, vii.

1909. "On a Palæolithic Instrument found in situ in the Cambridgeshire Gravel": GEOL. MAG., Dec. V, Vol. VI, pp. 534–7, Pl. XXXI.
(With W. G. FEARNSIDES) "The Howgill Fells and their Topography": Abs. Proc. Geol. Soc., 1908–9, p. 120; Quart. Journ. Geol. Soc., vol. lxv, pp. 587–610, figs., pls. xxviii–xxxi (rivers and glacial maps).

1910. "The Lake District and Neighbourhood: Lower Palæozoic, Upper Palæozoic, and Neozoic Times": Geol. Assoc., Jubilee Vol., pt. iii, pp. 624–60, figs.
(With W. G. FEARNSIDES) "Notes on the Lower Palæozoic Rocks of the Cautley District, Sedbergh (Yorks.)" (abstract): GEOL. MAG., Dec. V, Vol. VII, pp. 474–5.

1911. (With A. STURGE, NINA F. LAYARD, F. CORNER, W. WHITAKER, and W. C. UNDERWOOD) Report of the Special Committee on Sub-Crag Implements: Proc. Prehist. Soc. E. Anglia, 1897, vol. i, pp. 23–43, pls. ii–vii.

(With W. G. Fearnsides) "Notes on the Lower Palæozoic Rocks of the Cautley District (Sedbergh)": Rep. Brit. Assoc., 1910, vol. lxxx, p. 603.

1913. "The Lower Palæozoic Rocks of the Cautley District (Yorkshire)": Quart. Journ. Geol. Soc., vol. lxix, pp. 1–18.

"The Meres of Breckland": Proc. Camb. Phil. Soc., vol. xvii, pt. i (1913), pp. 58–61.

"A Late Palæolithic Site on Wretham Heath, near Thetford": Proc. Prehist. Soc. East Anglia, vol. i, pp. 374–7, pl. xcvi.

1914. "On the Preparation of a List of Characteristic Fossils": Rep. Brit. Assoc., 1913, p. 150, Interim Report of Committee.

1915. (With G. A. J. Cole, B. Hobson, J. Horne, G. A. Lebour, A. Strahan, W. W. Watts, and F. A. Bather, Sec.) Interim Report of Committee appointed to consider the Preparation of a List of Stratigraphical Names used in the British Isles in connection with the Lexicon of Stratigraphical Names in course of preparation by the International Geological Congress: Rep. Brit. Assoc., 1914, pp. 113–14.

(With W. G. Fearnsides, W. S. Boulton, E. S. Cobbold, V. C. Illing, and C. Lapworth) "The Lower Palæozoic Rocks of England and Wales. Report of the Committee appointed to excavate critical sections therein": Rep. Brit. Assoc., 1914, p. 115.

1916. "The Ashgillian Succession in the Tract to the West of Coniston Lake": Quart. Journ. Geol. Soc., vol. lxxi, pp. 189–204.

The Geology of the Lake District and the Scenery as influenced by Geological Structure, pp. x, 220, 51 text-illust., and map. Cambridge University Press.

II.—An Investigation of some Wealden Sands.

By Florence J. Relf, B.Sc.

(PLATE XII.)

THE sands which are the subject of this investigation were taken from various parts of the Wealden area, and from different horizons, though all, except the French ones, are below the Weald Clay and represent the lowest division of the Cretaceous rocks, that is, the Hastings Beds.

Fossils are rare in these sands, but carbonaceous material, indicating plant-remains, is common. The fossils in the Weald Clay are all (except some in the highest part) freshwater forms, and it is generally allowed that the Ashdown Sands are merely an introductory phase of the Wealden Beds. There is, therefore, no question that the whole of this series was deposited by fresh water. It was hoped, however, that an examination of the minerals in these sands might yield some evidence as to their source, and might even throw some light on the much discussed question as to the conditions under which they were deposited.

The comparisons that have been possible are extremely incomplete, and the results are far less definite than it was hoped they would be, but it is still believed that further and more thorough investigations along the same lines would help to a solution of the wider questions to which reference has been made, and that it may therefore be useful to record the results thus far obtained.

The sands originally investigated were taken from the Ashdown Sands of the Wealden area with a view to comparing, first, the sands of one horizon in different parts of the area, and secondly, a sequence

of sands in one district. Afterwards, some specimens from a higher horizon of the Hastings Beds in the Weald and some from the Wealden of the Isle of Wight were used. After these had been examined a short expedition was made to the districts around Calais and Boulogne, which form the eastern area of the Wealden deposits, in order to collect specimens for comparison with those found further west. This expedition was only carried out during the week preceding the outbreak of war, and the hope of visiting other French localities has had to be abandoned for the present.

The specimens examined include:—

Ashdown Sand.

(1) Seven successive bands from a pit near Forest Row.
(2) Ten, in two series, each of five successive bands, from Heathfield.
(3) Six in succession, from Battle.
(4) One from Bexhill.
(5) One from Eridge.
(6) Three from Lindfield.

Tunbridge Wells Sand.

Two specimens from south of Ardingley.

Wealden of Brook Bay, Isle of Wight.

One specimen.

Horizon doubtful—above Purbeck and below Gault.

S. Etienne au Mont, Equihen } south of Boulogne.
Wissant, south-west of Calais.

These last-named specimens were taken from beds which are generally considered to be representatives of our Wealden strata, though their exact horizon has not been determined.

In the field the sands are generally yellowish in colour, and iron-stained. Where the iron is abundant, highly resistant layers are formed, while, in some places, a regular ironstone—that formerly worked in Sussex—is present. Bands of more clayey material are common, while in some parts the usually fine sand is replaced by a conglomerate with pebbles reaching a diameter of about $\frac{1}{8}''$–$\frac{1}{4}''$.

Method of Investigation.

The method adopted in examining these sands was the usual one of separation by heavy fluids. The specimen was crushed in a mortar, a process rendered necessary by the amount of iron present, and then boiled in 20 per cent HCl to remove the irony accretions and so clean the grains. The removal of the iron was not always attained by this method. It was not necessary to sift the sands, for they were generally fairly uniform in grain. After treatment with acid the material was washed in running water to remove the mud; then it was filtered and dried. Next a separation was carried out in a solution of KI $Hg I_2$ of a specific gravity varying from 2·873 to 3·131 in order to separate the heavier minerals from the quartz, the commonest constituent of the sands.

In two cases a double separation was made, the material which came down in the potassium mercuric iodide being filtered, washed, and dried, and then put in a solution of cadmium borotungstate with

a s.g. of 3·317. This separated the heavier minerals from the tourmaline.

It was found advisable to use a fairly large quantity (10 to 20 grams) of sand to begin with, to ensure a greater degree of accuracy in subsequent calculations. In each case the proportion by weight of the heavy material was worked out and the size of the minerals noted.

As a result of these investigations it was found that the sands are composed chiefly of quartz, but that there is a small proportion of heavy minerals, notably of tourmaline and zircon. Other minerals found include felspar, rutile, anatase, staurolite, kyanite, garnet, and fluor.

WEIGHT OF HEAVY MATERIAL IN 1 GRAM OF SAND.

		Gram.	
Forest Row.	A	·003	
	B	·0015	
	C	·0023	Average ·0014.
	E	·0003	
	F	·0003	
Battle.	A	·0015	
	B	·001	
	C	·0007	
	E	·0022	Average ·0016.
	F	·003	
	G	·0012	
Eridge.	E	·0008	
Lindfield.	B	·0052	Average ·0071.
	J	·009	
Ardingley.	A	·0025	Average ·0022.
	B	·002	
Equihen.	C	·0008	
Wissant.	D	·0004	

RESULTS OF DOUBLE SEPARATION.

Forest Row. C.

Of the material with s.g. above 3·131, 22 per cent had s.g. lower than 3·317 (this was mainly tourmaline), and 78 per cent higher than 3·317 (this was mainly zircon).

MINERALS.

Quartz.—The quartz grains vary in size from ·03 mm. to ·13 mm., the average being about ·07 mm. They are usually angular, though occasionally they are sub-rounded. The grains generally contain inclusions which are not, as a rule, arranged in any definite lines.

Felspar.—Orthoclase felspar is present in very small quantity only. As the result of an attempt to separate this mineral from the quartz by specific gravity, after the minerals heavier than quartz had been removed, it was found that the amount of felspar obtained from about 10 grams of the material was barely sufficient to weigh, there being only enough material to mount under one small coverslip. The felspar fragments are, on the whole, much smaller than the quartz, and, as is usual with very small fragments, they are even less rounded.

Zircon.—The zircon crystals in the sands show, as they commonly do, very good crystal shape, and they are seldom broken. The individual crystals vary, however, and four types have been noted:—

(1) Crystals long, length four or five times breadth, with sharply pointed pyramids developed at both sides. (Pl. XII, Fig. 1.)

(2) Crystals short, length about twice the breadth, with pyramids at both ends.

(3) Crystals with only one pyramid developed. These may show a basal plane at the other end, or they may appear irregular at that part, as though broken off (as they would look if they had grown in a cavity). (Pl. XII, Fig. 2.)

(4) The fourth type is a modification of types (2) and (3), and includes short crystals rounded at the ends, making the whole fragment oval in shape.

Of these, type (2) seems to be commonest. Many crystals have inclusions; a few show zoning.

Some idea of the abundance of zircon crystals can be obtained from the results of counting in the case of eleven specimens from Heathfield. In 1 gm. of sand the zircons varied in number from 55 to 877, the average being 288. Though the figures are certainly not accurate they serve to show that the mineral is common among the heavy constituents. In the heaviest portion of the sand (s.g. above 3·317) it is the predominant mineral. The size of the crystals is fairly constant, the length varying, in the examples measured, between ·04 to ·09 mm.

Tourmaline.—Next to zircon, among the heavy minerals of these sands, tourmaline is the most abundant, and the blue and the brown varieties are present. The brown tourmalines are generally larger than the blue ones, and they have quite irregular outlines. The blue ones are as usual more definite in shape, often showing a tendency to prismatic form. Individuals of both varieties are generally broken, but seldom rounded. (Pl. XII, Fig. 3.) Their size is less variable than that of the quartz grains, being from ·05 mm. to ·1 mm. As a result of the counting previously referred to, the number of tourmaline grains per gram of sand was found to vary from 12 to 105, the average being 58, far less than the number of zircons.

Rutile comes next in point of abundance. The crystal shape is generally good, and the characteristic geniculate twinning is occasionally recognizable.

Staurolite.—This mineral is rare, but a little was identified in the sand from Lindfield, and more in that obtained from west of Bexhill.

Kyanite also is rare, and was only found in the Bexhill specimens and in those from France. (Pl. XII, Fig. 5.)

Anatase, although not common in these sands, was recognized in the Bexhill and Lindfield samples. Some crystals show the striated steep pyramid-faces, and others are tabular. (Pl. XII, Fig. 4.)

Garnets were only recognized in the Lindfield Sands.

Fluor was identified in one of the Lindfield samples.

As the materials found in these sands make it probable that the rocks from which they were originally derived were of granitic character, it was decided to powder some granite and to attempt a separation of its heavy minerals by the same method as that used for the sands. The granite chosen was from Corndon, Dartmoor, this being the nearest granitic area to the Weald. It was crushed in

a mortar, and sifted through muslin. This method has been adopted at Bedford College, because it is difficult to ensure that no foreign grains are clinging to an ordinary sieve. The fine material was washed to remove the mud, treated with acid, and finally separated in $KI\,Hg\,I_2$. As a result it was found that nearly all the heavy particles consisted of brown tourmaline, generally irregular in shape, but occasionally prismatic. Zircon crystals were comparatively rare. Some corundum was found. The rarity of free zircon would, of course, be explained by the fact that it commonly occurs included in quartz and biotite, which in this case was not broken up.

On the whole, the result of this examination confirms the idea that the sands were mainly derived from a granitic rock. It remains to seek a large area occupied by suitable rocks, and exposed to denudation in the early part of the Wealden period.

During Jurassic times there was probably a large land area to the west and south-west of the present position of Great Britain. This land included the western mountainous districts of Wales, the Cornwall and Devon Peninsula, and the north-western peninsula of France; but these portions of modern Europe represent the eastern seaboard only of the supposed continent, which is thought to have extended into Ireland, and far to the south-west and north. It is the area referred to by Professor Bonney,[1] in an article on "Pebbles in the Trias", as "the ancient mass of Archæan crystallines, which once swept round the Scoto-Scandinavian region to north-western France". In the Portland epoch the borders of this land extended eastward into Dorsetshire, and in the succeeding Purbeck and Wealden periods, continued upheaval had still further increased the land area.

When the Ashdown Sands were being deposited, the greater part of England must, therefore, have been land covered by Jurassic deposits, that is, mainly by dark shales and limestones—not the kind of material from which a quartz sand could be derived. The only parts not covered by Jurassic rocks were the areas which had formed part of the western continent, with, perhaps, a fringe of Triassic rocks; and the extreme east of England, north-east of the London Basin. As far as can be judged by borings in this eastern district (at Harwich and Ware, for example), this land area seems to have been formed, at that time, by rocks of Silurian and Devonian formations, which were composed of beds of shale, with thin beds of limestone in the Silurian and of grey and red sandstone or quartzite in the Devonian.

It seems, therefore, fair to conclude that the source of supply of the sands under consideration must be sought among the rocks of the western continent. In the remains of it which have survived to the present time are masses of granitic rock, and from such rocks there is, as we have seen, no difficulty, mineralogically, in deriving the Wealden Sands.

The general angularity of the fragments makes it probable that the material was brought directly from the granitic rock to its present

[1] Professor Bonney, "Pebbles in the Trias": GEOL. MAG., Dec. IV, Vol. II, 1895.

position, and not from any intermediate sandstone. The only sandstone which need be considered in this connexion is the Trias of the West and Midlands; but according to Dr. Thomas[1] the quartz grains in this formation are more rounded than those of the Wealden Sands, not less so, as must have been the case if the Wealden material had been carried from the Trias areas. Further, it is probable that, at that time, the Trias rocks were covered by Jurassic deposits which have since been denuded. Any river flowing eastward from the western land would naturally flow over these Jurassic rocks, and would carry away some of their material. That so little of it is now found in the sands would be explained by its generally calcareous nature.

Some interesting specimens were found, however, in the Ashdown Sand from the neighbourhood of Lindfield, whose nature seems to indicate a derivation from Jurassic rock. In a sandpit north-east of Lindfield, east of Paxhill (the most westerly area considered in the Wealden district), is a layer in which the size of the fragments reaches $\frac{1}{8}''$–$\frac{1}{4}''$. They are, in fact, small pebbles firmly cemented to form a conglomerate. The pebbles in this conglomerate have been examined in microscope slides, as well as in the hand-specimen, and are found to consist mainly of quartz, some being vein quartz. But, in addition to these, are certain small lumps of white earthy-looking material. These are evidently the fragments to which Topley refers as "white chalky-looking stuff".[2] Some of it breaks easily in a powdery fashion, but it is not soluble in H Cl, and when the hardness of some of the less powdery pieces was tested it was found impossible to scratch them with a penknife. The white material is evidently not calcium carbonate. In some pieces the powdery character is confined to the outside, the inside appearing chalcedonic. Under the microscope the white crumbly stuff was found to have a great resemblance to decomposing chert, and a gradation seemed traceable from this to a normal chert pebble. This discovery led to a comparison with several slides[3] of Jurassic chert from the Vale of Wardour and the Isle of Portland, and the comparison confirmed this opinion and showed that the Lindfield fragments closely resemble the Isle of Portland chert. Further search with a lens, in the hand-specimens, and with microscope revealed small pebbles with the oolitic structure and decided cherty appearance common in these Jurassic rocks. (Pl. XII, Fig. 6.) The presence of this material therefore strengthens the view that the water bearing the Ashdown Sands came from a westerly direction.

It may be noted here that at Lindfield there are found a greater proportion of heavy minerals, larger fragments, and more variety of material—especially among the heavy minerals—than there are elsewhere in the Weald. This points to the probability that here we are near the middle of the old Wealden Channel.

The west to east extension of the Wealden beds gives additional

[1] Dr. H. H. Thomas, "Petrography of the New Red Sandstone": Q.J.G.S., 1909.

[2] W. E. Topley, *The Weald* (Survey Memoir), p. 84.

[3] These slides were kindly placed at my disposal by Dr. C. A. Raisin at Bedford College.

support to the view that the stream bearing their material came from a westerly direction. If it did—and this was Jukes-Browne's view—it would, of course, be probable that tributaries joined it on its way to the southern sea. A tributary from the north-west coming over the Trias rocks of the Midlands may have brought the pebbles of liver-coloured quartzite mentioned by Lamplugh[1] as occurring in a boring at Dover, and considered by him to have come from the north-east.

On the whole, this study of the minerals in the Ashdown Sands points to the conclusion that the majority of the material was brought by a large river from the west or south-west. On the question as to whether the Wealden beds were laid down in a lake or as a delta, the results of the investigation have been disappointing. Although the Wealden river is believed finally to have reached the sea which then occupied the Mediterranean area, the only known estuarine deposits of that age which are of any considerable importance are those in the Haute Marne district. If the Wealden river and the Southern Sea were connected through this area, the subsequent invasion of the Vectian sea north-westward would have been the natural one of advance up a river valley.

If the theory that the Wealden river broadened into a lake be accepted, an outflowing stream must be supposed to have emerged from the south-east end, and this stream to have broadened into a delta which was subject to invasion by the sea. If the lake did exist, the stream emerging from it must have been fairly free from sediment, and the thinning of the Wealden deposits, eastward, bears out this view. In this case it is difficult to imagine how all the material necessary to the formation of deltaic deposits could have been accumulated between the lake and the sea. It is true that the Haute-Marne estuarine series is only about 60 feet thick, but it extends over a fairly wide area, and represents a greater amount of erosion than seems possible between the lake and the delta, unless a stream from another direction joined in at this point; and of this there is, I believe, no evidence.

On the other theory—that our Wealden Series is estuarine—the assumption is that the deposits are only part of the wide estuary, of whose lower end there are still remains in France. The alternation of clay and sandy material, and the facts that the Weald Clay is less sandy than the underlying Ashdown Sands and that current bedding frequently occurs, are characteristic of lake as well as of delta deposits, if the lake is fed by streams with fairly swift current; while the absence of rock-salt and gypsum is no proof that a lake did not exist. The absence of marine bands from all but the upper part of the Wealden Series has been used as an argument against their being estuarine, but if this area was but the upper end of a delta their absence from the lower and presence in the higher horizon is but natural. De Lapparent held the estuarine view, and he stated that the river in question is only one of several which entered the sea from the north.

[1] G. W. Lamplugh, *Mesozoic Rocks in Coal Explorations in Kent*, p. 19.

Whichever theory is held, there is always the difficulty of the gap between the undoubted estuarine deposits of France and the English freshwater beds on the one side, and the marine deposits of the south on the other, and unless these gaps can be bridged it is doubtful whether any definite solution of the problem can be found.

I have to thank Dr. H. H. Thomas for his kindness in looking at the slides and reading the manuscript. I have also to offer my thanks for being allowed to carry on this work at Bedford College; and especially to Miss Raisin for much help throughout the investigation.

EXPLANATION OF PLATE XII.

FIG.

1. Heavy grains from Ashdown Sand of Forest Row (separated by heavy fluid, s.g. 3·0317), showing slender zircon crystals, one terminated by a pyramid at each end. × 60, approx.
2. Heavy grains from Hastings Sand of Bexhill (separated by heavy fluid, s.g. 3·292), showing zircon crystal with inclusions. Crystal terminated at one end by pyramid faces and at the other probably by a basal plane. × 90, approx.
3. Grains of Ashdown Sand from Forest Row, sinking in solution of mercuric potassium iodide (s.g. 3·0317), but floating on solution of cadmium borotungstate (s.g. 3·317), showing mainly tourmaline. × 30, approx.
4. Heavy grains from Tunbridge Wells Sand of Lindfield (separated by heavy fluid, s.g. 3·035), showing tabular crystal of anatase. × 85, approx.
5. Heavy grains from Wealden Sand of Equihen (Boulonnais) (separated by heavy fluid, s.g. 3·035), showing kyanite with cleavages. × 80, approx.
6. Section of conglomerate in Tunbridge Wells Sand from Lindfield, containing one small pebble of chert, showing structures which include one spiral organism. × 20, approx.

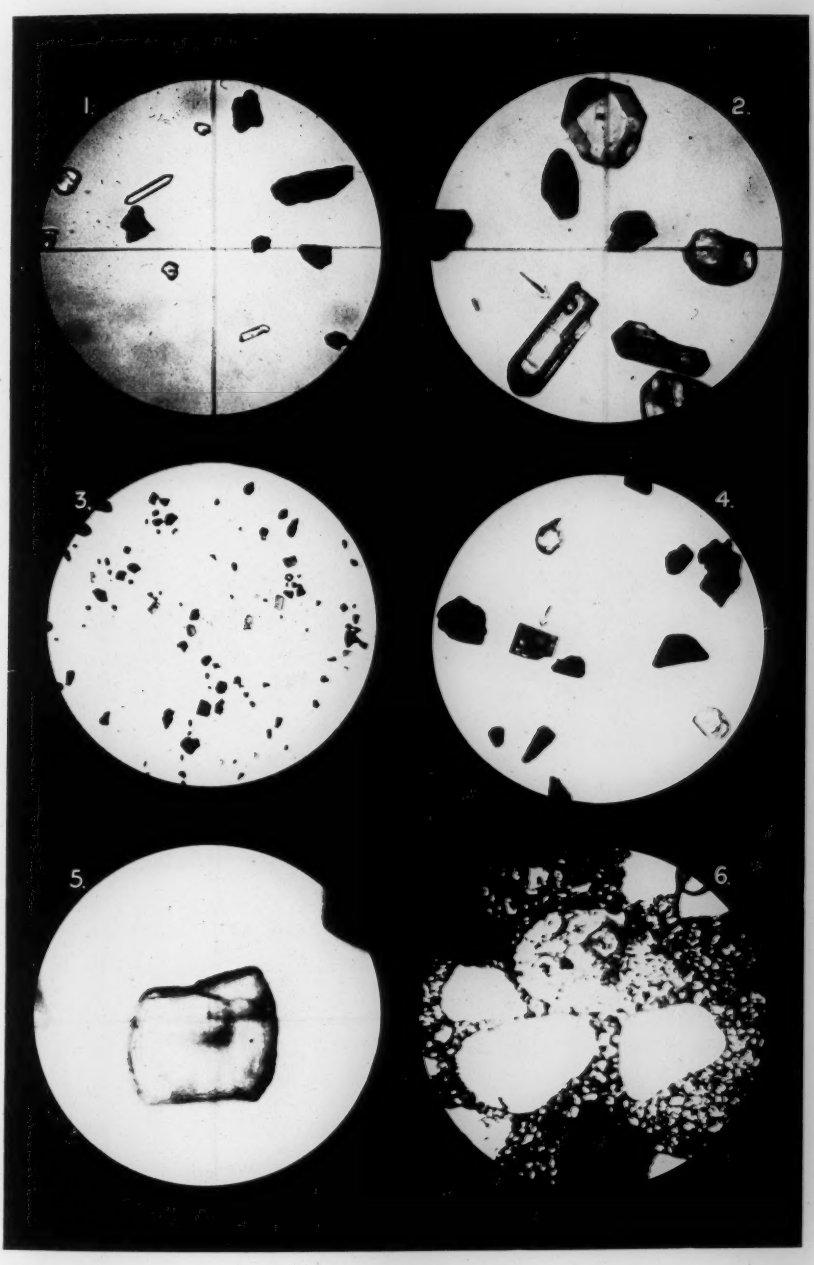
III.—A CIDARID FROM THE HARTWELL CLAY.

By F. A. BATHER, M.A., D.Sc., F.R.S.

(Published by permission of the Trustees of the British Museum.)

REMAINS of Echinoderms are so rare in the Hartwell Clay of Buckinghamshire, and when found so fragmentary, that it may be worth while drawing attention to a small piece of an Echinoid test recently obtained from the Hartwell Brick-pit by Mr. Edwin Hollis, F.Z.S., curator of the Aylesbury Museum, and presented by him to the national collection (Brit. Mus., Geol. Dept., E 12241). The terminology of the following description is that defined on pages 59–65 of my "Triassic Echinoderms of Bakony", Budapest, 1909.

The fragment represents the greater part of two adjacent interambulacral plates of a Cidarid. The portion missing is the adradial tract. It can be inferred from the faces of the transverse sutures that these plates come from the right-hand (or *b*) column of the interambulacrum. In the interradial suture-margin of each plate the apicad limb is about twice the length of the orad limb, whence it may be inferred that the plates come from above the ambitus. But since the height of the lower plate is slightly less than that of the upper, they cannot have been far above the ambitus.



SOME WEALDEN SANDS.

The measurements in millimetres are as follows:—

	Upper plate.	Lower plate.
Height	6·5	6·05
Apicad-interradial margin	4·6	4·3
Orad-interradial margin	2·1	2·3
Height of scrobicular circle	6·0	
Width ,, ,,	7·+	
Diameter of boss (ill-defined, say)	5·8	
Width of scrobicule ,, ,,	0·7	
Diameter of platform	3·1	
Vertical diameter of mamelon	1·8	
Transverse ,, ,,	1·65	

From this it will be seen that the scrobicular circle is compressed, so as to be somewhat elliptical transversely; the scrobicules, however, remain distinct. Taking the general thickness of the extra-scrobicular region as 1·4 mm., including the tops of the secondary tubercles, the boss rises, with a slightly convex curve, to a platform at 1 mm. above this. The platform is marked with twelve distinct crenellæ. The mamelon, which expands slightly, reaches ·8 mm. above this.

The interradial tract is covered with secondary tubercles, of which five lie in a lineal space of 4·4 mm. They tend to run in lines approximately parallel to the two limbs of the interradial margin. The boss of a secondary tubercle may have a diameter of as much as ·7 mm. Between the secondary tubercles are scattered much smaller tertiary tubercles, which occasionally form partial scrobicular rings.

The main tubercle can hardly be said to have a ring of scrobicular tubercles, for the tubercles surrounding the scrobicule are certainly not larger or more regular than the other secondary tubercles. Indeed, they seem in some cases to be smaller, as though invaded by the main scrobicule. On the intertubercular tract bordering the apicad margin of the upper plate there can be distinguished a line of these tubercles, gradually diminishing in size. On the corresponding tract of the lower plate there is an irregular ridge, but the tubercles from which it has been derived have atrophied.

The species which this specimen most resembles are two found near Boulogne-sur-mer, namely *Cidaris legayi* Sauvage & Rigaux (1872) and *Cidaris boloniensis* [melius *bononiensis*] Wright (1857), neither of which has yet been recorded from England. Descriptions, drawings, and bibliography of these will be found in G. Cotteau, Paléontologie Française, Jurassique, vol. x, part 1, Echinides Réguliers, pp. 214 (1877) to 226 (1878), pls. 200–202. In *C. bononiensis*, as compared with the present specimen, the scrobicules are more distinct, the scrobicular ring more complete, and the scrobicular tubercles more developed in comparison with the other secondary tubercles. In *C. legayi*, Cotteau's figure shows the scrobicular tubercles as less pronounced than in *C. bononiensis*, but still as more pronounced than the secondaries; his text, however, states that they are of almost the same size as the latter. Our specimen therefore seems to lie between these two species, but rather on the side of *C. legayi*.

C. bononiensis comes from the Kimmeridgian, *C. legayi* from the Portlandian zone of *Ostrea expansa*, that is to say, the Upper Portlandian. The Hartwell Clay is generally regarded as Lower

Portlandian. We are therefore justified in regarding the present specimen as a mutation from *C. bononiensis* to *C. legayi*, and we may refrain from giving it an independent name.

A list of fossils from the Hartwell Clay was published on p. 227 of the Geological Survey Memoir on the Jurassic Rocks (1895), but this records no echinoderm other than *Pentacrinus*, which name refers, no doubt, to columnals of *Isocrinus*, since the true *Pentacrinus* is not known later than the Corallian age.

There are, however, other echinoderms from the Hartwell Clay, and if they were omitted from the list just quoted it is probably because Wright said that they came from the Kimmeridgian, to which in his time the Hartwell Clay was referred. They are the following.

Hemipedina morrisi T. Wright, Sept. 1855, Ann. Mag. Nat. Hist., ser. 2, vol. xvi, p. 197. Holotype, a fragment of test figured by Wright (April, 1858, Palaeont. Soc. Monogr. Ool. Echinoidea, p. 166, pl. xii, figs. 2 *a*, *b*), in the Geological Dept. of the British Museum, regd. E 8800. The radioles referred to this species by Wright (1858, p. 167) are in the same Department, regd. 56879. Other tests are registered E 8801–8803.

Hemipedina cunningtoni T. Wright, Sept. 1855, Ann. Mag. Nat. Hist., ser. 2, vol. xvi, p. 198. Holotype, a fragment of test figured by Wright (April, 1858, Palaeont. Soc. Monogr. Ool. Echinoidea, p. 167, pl. xii, figs. 3 *a*, *b*), in the Geological Dept. of the British Museum, regd. 34567.

"*Cidaris spinosa*, Agassiz": radioles provisionally referred to this species by T. Wright in 1857 (Palaeont. Soc. Monogr., p. 53), of which one was figured in 1858 (op. cit., pl. xii, fig. 6, not 4* as in the legend, where the reference numbers are in great confusion). Examples of these radioles are in the Geological Dept. of the British Museum, regd. 34566 & 57029; others, collected by Mr. Zedekiah Hunt, are in the Aylesbury Museum. The true *Cidaris spinosa* is an Oxfordian species, so it was never likely that these radioles belonged to it. They agree closely with the radioles of *Cidaris legayi*, and doubtless belong to the same mutation *C. legayi/bononiensis* as the interambulacrals now at last discovered by Mr. Hollis.

IV.—The Crystalline Rock-areas of the Piémontese Alps.

II. Northern Piémont.

By C. S. Du Riche Preller, M.A., Ph.D., M.I.E.E., F.G.S., F.R.S.E.

IN the preceding paper[1] I described the crystalline rock-areas of the Maritime and Cottian Alps: I now proceed to briefly review those of Northern Piémont forming part of the Grajan and Pennine Alps, under three heads—

I. The Lanzo Valleys and Gran Paradiso Groups.
II. The Dora Baltea (Val d'Aosta) Area.
III. The Lanzo, Ivrea, and Val Sesia Area.

They are shown in the sketch-map, Fig. 1. The conclusions in reference to the combined areas of the Piémontese Alps will be stated at the end of the present paper.

[1] Geol. Mag., May and June, 1916, pp. 198–205, 250–5.

I. The Lanzo Valleys and Gran Paradiso Groups.

1. *The Lanzo Valleys* (Figs. 1 and 3).—The Stura di Lanzo emerges from the Alps and enters the Po Plain close to the town of Lanzo (540 m.) about 30 kilometres north-west of Turin, and discharges into the Po a short distance below that city. The point of exit lies immediately west of Lanzo, where the Stura cuts through a lherzolite wall 400 metres in height. This defile, or *chiusa*, of St. Ignazio, 3 kilometres in length, thus forms the gateway and drainage exit of what is indisputably the largest, most concentrated, and most diversified pietre verdi area in the Alps, covering, as it does, no less than 600 square kilometres or about 240 square miles. Immediately west of the St. Ignazio defile the Stura divides into two branches—the southern or Stura d'Usseglio, and the northern or Stura Val Grande—from which latter branches off, a few kilometres higher up, at Ceres, the western arm or Stura di Balme. The more or less parallel courses of the three torrents from their sources to their confluence near St. Ignazio are from 20 to 30 kilometres in length. The Usseglio Stura rises in Rocciamelone (3,557 m.), the middle or Balme Stura descends from Uja Bessanese (3,622 m.) and Uja Ciamarella (3,670 m.), and the Val Grande Stura has its source in La Levanna (3,555 m.). Of these four mountains, forming a crest-line of barely 15 kilometres south to north along the Franco-Italian frontier, the first three constitute a formidable calc-schist massif, while the treble-peaked Levanna forms part of the Gran Paradiso gneiss massif. The Usseglio and Balme Sturas have eroded their beds chiefly in pietre verdi, while the Val Grande branch lies, in its upper part, exclusively in the gneiss formation, and traverses pietre verdi masses only in its lower course. The floors of the three valleys are from 1,000 to 2,000 metres below the crest-lines of the dividing ridges with steep, often almost vertical mountain sides.[1]

As is seen from the sketch-plan, Fig. 3, the drainage area of the Lanzo valleys forms approximately a rectangle about 30 by 20 kilometres in length and width, enclosed by four ridges whose extreme points are Rocciamelone and Levanna on the west and Monte Arpone, Lanzo, and Cima Angiolino on the east.[2] Within these ridges, the Lanzo valleys with their three parallel divides form a trough or syncline of pietre verdi in two unequal parts: the larger, western part, about two-thirds of the whole, which lies in the calc-schist, and the smaller, eastern part, about one-third of the whole, which lies in the mica-schist formation. These two juxtaposed divisions or old centres of eruption of different age are separated by a narrow strip of calc-schist running south to north from Monte

[1] The three Stura valleys, as also the Orco Valley (Gran Paradiso), are easily accessible by roads leading to Usseglio, Balme, Forno, and Ceresole at the upper ends, 1,265, 1,458, 1,226, and 1,613 m. altitude respectively. The Usseglio and Balme Valleys are also known as the Viù and Ala Valleys respectively.

[2] The short valley of the Tesso, immediately north of Lanzo, lies, strictly speaking, outside the drainage area of the St. Ignazio defile, but the torrent, rising in Cima Angiolino, belongs to the Stura watershed and forms part of the Lanzo valleys.

Fig. 1. Sketch Map of Crystalline Rock Areas, Northern Piémont.

PV = pietre verdi; D = diorite; gr = granite; por = porphyrite; sy = syenite; s = peridotite and serpentine; gn = gneiss; MS = mica-schist. Del: D.R.P.

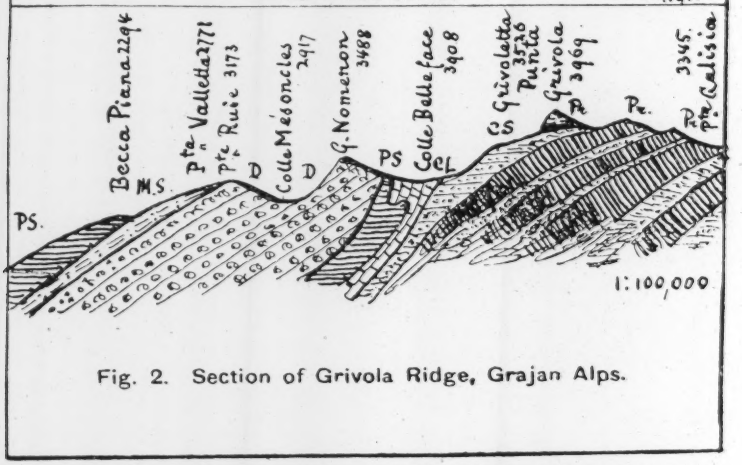


Fig. 2. Section of Grivola Ridge, Grajan Alps.

PS = Permo-Carboniferous schist; MS = mica-schist; D = diorite; CL = crystalline limestone; CS = calc-schist; Pr = prasinites.

Arpone to Ceres and Monte Bellavarda, as shown in Fig. 3. On the north, the western division is bounded by the Gran Paradiso gneiss, and the eastern division by mica-schist and minute gneiss. The Paradiso gneiss, being the fundamental substratum, probably extends south below the calc-schists and pietre verdi to the Dora–Maira gneiss massif; the mica-schist formation with pietre verdi is the continuation of the Rocciacorba and Avigliana belt south of the Lanzo valleys and extends north-east from Lanzo to Ivrea and Val Sesia. The calc-schists are in evidence chiefly at the lower levels of the valleys where they alternate with pietre verdi; at the higher levels and on the crest-lines they are very subordinate, and, except on the western ridge from Rocciamelone to Ciamarella, and in the dividing strip already mentioned, appear only in the eroded gaps or saddles of the more resistant pietre verdi masses.

From Mattirolo's beautiful "geo-lithological" contour-map of the Lanzo valleys 1 : 100,000 (1904),[1] the distribution of the crystalline rocks of the entire area works out approximately as follows:—[2]

		sq. km.		per cent
Lias–Trias (western division)	Calc-schist with crystalline limestone	48	=	8
	Pietre verdi	240	=	40
Permo-Carboniferous (eastern division)	Mica-schist and minute gneiss	96	=	16
	Pietre verdi	120	=	20
Pre-Carboniferous.	Gran Paradiso gneiss	96	=	16
		600		100

The pietre verdi of the two divisions thus represent collectively no less than two-thirds of the aggregate area. The lithological distribution of those masses, intercalated in, and resting on the crystalline schists, is extremely complex, for, except the transverse dividing line already mentioned, there is in their kaleidoscopic association no demarcation, sequence, or distinction of level. Yet, on closer examination, the broad limits of certain groups can be defined along the four parallel ridges which, flanking and separating the three valleys, run west to east and converge at the Lanzo defile. The principal groups, generally circumscribed by morainic, alluvial, and detritus belts round their bases, are shown in the plan, Fig. 3, and specified in the following table, in which the names and altitudes refer only to the culminating points. In almost every case the groups, varying in area from 5 to 20 square kilometres, comprise a cluster of minor peaks and spurs, and alike by their formidable bulk and their often pinnacled crests attest the great resistance of pietre verdi to denudation, to which the once overlying crystalline sedimentary schists more readily and long since succumbed.[3]

[1] Boll. R. Com. geol., 1905, p. 191. At the time of the compilation of this map all the crystalline rocks of the Lanzo valleys were still considered of Archæan age without distinction between the age of the mica-schist and the calc-schist formation, the new classification dating from 1911.

[2] The earlier works dealing with the Lanzo valleys, etc., by Gastaldi, Strüver, Baretti, and Bucca from 1871 to 1886 were already quoted in the preceding papers.

[3] The local designations Uja, Ciama, Punta, Becca, Bric, Truc, Torre, Rocca, etc., all denote point, peak, summit, crest, crag, etc.

DISTRIBUTION OF PIETRE VERDI IN THE LANZO VALLEYS.

RIDGE I, from Rocciamelone to Lanzo, on right of Usseglio Valley; 36 km.

Serpentine: Gran Uja (2,686 m.); Civrari (2,302 m.).

Peridotite, lherzolite, and serpentine: Arpone (1,600 m.); Roc Neir (1,516 m.).

RIDGE II, from Croce Rossa to Lanzo, between Usseglio and Balme Valleys; 30 km.

Amphibolites, prasinites, and euphodites: Torre d'Ovarda (3,075 m.); M. Ciaron (1,863 m.).

Serpentine: Becca Nona (2,765 m.); Morosa (2,135 m.); Calcante (1,644 m.).

RIDGE III, from Ciamarella to Lanzo, between Balme and Grande Valleys; 30 km.

Serpentine: Uja Mondrone (2,964 m.); Rosso (1,774 m.).

Amphibolites, prasinites, and euphodites: Doubia (2,464 m.); Plù (2,201 m.).

RIDGE IV, from Levanna to Lanzo, on left of Val Grande; 36 km.

Amphibolites, prasinites, and euphodites: Bellavarda (2,345 m.).

On the whole, serpentines predominate in the first, amphibolites, prasinites, and euphodites in the second ridge, while in the third the two series are about equal, and in the fourth they are only represented by the Bellavarda complex wedged between the gneiss formation on the left and the mica-schists on the right. The two series of the calc-schist horizon share their aggregate area of about 240 square kilometres in fairly equal proportions; that of the eastern or mica-schist horizon, occupying 120 square kilometres, is about equally divided between the nucleus of peridotite and lherzolite, and the surrounding belt of serpentine with associated euphodite.

The pietre verdi of the Lanzo valleys appear in all their varieties and at all levels from 500 m. altitude at Lanzo, which town is built on serpentine, up to 3,500 metres on the highest points of the central and enclosing ridges. At the lower levels, more especially in the central part of the synclinal trough, they alternate conformably with calc-schist and crystalline limestone intercalations, having shared in the acute folding and contortions of the latter; while at the higher levels they form enormous banks, cliffs, and bastions like separate massifs, such as the serpentine complexes of Gran Uja, Civrari, Becca di Nona, and Uja di Mondrone, and, again, the amphibolic, prasinitic, and euphoditic groups of Torre d'Ovarda, Ciaron, Doubia, and Bellavarda mentioned in the table.

The chloritic prasinite known as ovardite and mentioned in the preceding papers takes its name from the Torre d'Ovarda group in the Balme Valley, which latter is, moreover, famed for its splendid specimens of garnet, epidote, and other crystals. All the pietre verdi of more or less secondary composition and their schists present their usual actinolitic, glaucophanic, zoisitic, chloritic, and talcose varieties, and are often garnetiferous and eclogitic. They all exhibit the usual marked tendency to chloritic decomposition, i.e. to pseudo-serpentine or serpentinous schist, a phenomenon which applies equally to the

peridotites, lherzolites and associated euphodites of the eastern or mica-schist horizon. In neither horizon do the euphodites appear as deep-seated rocks; they are, on the contrary, associated and interstratified with the other pietre verdi at all levels, overlying and underlying, and intercalated in them and the crystalline sedimentary schists quite as often as vice versa. As in the areas of the Maritime and Cottian Alps previously described, so also in the Lanzo valleys the pietre verdi constitute two distinct, juxtaposed, and eminently magnesian series of eruptive and submarine origin, contemporaneous respectively with the Mesozoic calc-schist and the Permo-Carboniferous mica-schist formations with which they are intimately associated, and jointly with which they have for long periods been subjected to repeated earth-movements, folding, and intense pressure-, heat-, and hydro-metamorphism.[1]

2. *The Gran Paradiso Massif* (Fig. 1).—This oval-shaped complex, about 30 by 20 kilometres in length and width, is bordered on the south by the Lanzo valleys and on the north by the Dora Baltea watershed. At its southern extremity it is traversed by the Val Grande Stura already referred to, while its central part is intersected west to east by the Orco, which rises in Punta Galisia (3,345 m.) and with its affluent the Soana discharges into the Po. In the northern part rise the Cogne and Savaranche torrents, both of which drain into the Dora Baltea near Villeneuve, above Aosta. The Orco Valley has cut the original dome-shaped massif into two more or less parallel ridges, the southern from the treble-peaked Levanna to Monte Tovo (2,575 m.), and the northern which, starting from Punta Galisia, culminates in the classic ellipsoid or flat cupola of Gran Paradiso proper (4,061 m.), the highest point of the Grajan Alps.

The massif is composed of three more or less concentric masses, viz., a nucleus of primitive, granitoid, porphyroid, glandular, and eye-gneiss with large felspar crystals up to 10 centimetres, surrounded by an inner belt of smaller-grained, schistose, biotitic gneiss with green nodules, and an outer belt of mica-schist and minute gneiss, often with white mica. Of the biotitic gneiss a large lenticular mass in the primitive gneiss crops out at Ceresole (1,613 m.) in the upper Orco Valley, between La Levanna and Gran Paradiso. In this, the central part of the massif, the gneiss is bedded horizontally as the practically undisturbed fundamental substratum; only the outer belt, more especially at the southern extremity, has shared in the folding and dipping of the Lanzo Valley region.[2] In juxtaposition to the

[1] In a valuable memoir, "Contribuzione allo studio delle roccie a glaucofane, etc., Liguria e Alpi Occid.," Boll. R. Com. geol., 1903, p. 255 et seq., S. Franchi has shown that the crystalline sedimentary rocks of the Piémontese Alps, such as silico-calcareous schists (diaspri), quartzites, calc-schists and limestone, mica-schists, phyllites, and minute gneiss, contain glaucophane, epidote, sismondina, zoisite, chlorite, albite, and other secondary minerals as the result of metamorphism of associated and intercalated eruptive material.

[2] Novarese found a granite vein in a large erratic gneiss block near the Sea Glacier (2,500 m.) in the south-west corner of the Paradiso massif, which may therefore contain intrusive granite, like the Argentera massif in the Maritime Alps. V. Novarese, "Rilevamento Valli Orco e Soana, Alpi Occid.": Boll. R. Com. geol., 1894, p. 215 et seq. A. Stella, "Rilevamento Valle Orco, Alpi Occid.": ibid., p. 343 et seq.

outer belt, a more or less continuous fringe of calc-schist and pietre verdi extends all round the periphery of the massif, stretching from Monte Bellavarda in the Stura Grande Valley north to the Orco and Cogne Valleys and thence north-east to the Champorcher and Clavalité Valleys, where it forms a separate, considerable area. Throughout this belt, the pietre verdi present all the varieties of those of the Lanzo valleys, including more especially glaucophanic amphibolites and omphacitic eclogite. Along its eastern margin this calc-schist and pietre verdi belt is contiguous to the mica-schist horizon with large intercalations of minute and tabular gneiss conspicuous by its green mica; in the Lanzo valleys this gneiss is quarried near Pessinetto, between Lanzo and Ceres. The eastern spurs of the mica-schist area form part of the Lanzo–Ivrea belt to be described later.

II. The Dora Baltea Area.

The Val d'Aosta comprises in its middle course important pietre verdi groups, both on the right and left of the Dora Baltea. On the right the most remarkable areas are those of Punta Grivola, Monte Emilius, and Monte Rafré, and on the left the Mont Mary group.[1]

1. *The Grivola Area* (Figs. 1 and 2).—About 10 kilometres north of Gran Paradiso, but outside the gneiss massif, and in the surrounding calc-schist formation, rises the Grivola peak (3,969 m.), which in its pyramidal grandeur vies with Matterhorn and Monte Viso. Its position is rendered the more commanding by the scooped out valleys of the Cogne on its eastern and northern, and of the Savaranche on its western flank, both of which torrents, as already mentioned, rise in the Paradiso massif and discharge into the Dora Baltea near Villeneuve (670 m.). The ridge which rises from Villeneuve[2] between the two valleys to the crest of Grivola and Grivoletta (3,526 m.) in a horizontal distance of 12 kilometres presents, in an interesting natural section, a complete sequence of rock formations which, in ascending order, may be summarized as follows:—

		Superficial width. km.	Altitude. m.
Villeneuve.	*Lias and Trias:* Fossiliferous limestone, ordinary facies	4	700
	Calc-schist and crystalline limestone		2,000
Becca Piana.	*Permo-Carboniferous:* Sericitic, graphitic, gneissiform, and psammitic schist	1	2,800
Gran Nomenon.	Sphenic diorite	4	3,500
	Sericitic, graphitic, gneissiform, and psammitic schist	1	3,500
Grivola.	*Lias and Trias:* Crystalline limestone, calc-schist, and prasinites	2	3,900
		12	3,200

[1] The whole region between the Aosta and Orco Valleys, including the Paradiso massif, is, perhaps more than any other part of the Piémontese Alps, rendered conveniently accessible by the numerous mule paths of the Royal shooting preserves. An excellent topographical map of the Val d'Aosta, Lanzo, and Ivrea region, 1 : 250,000, is that by V. Novarese in Boll. R. Com. geol., 1913–14, p. 244, "Il Quarternario Valle d'Aosta e Valli Canavesi."

[2] Villeneuve is one of the localities where S. Franchi found fossils in Triassic limestone intercalated in calc-schists. "Terreni secondarie facies Piémontese": Boll. R. Com. geol., 1909, p. 526 et seq.

The upper part of this section is shown in Fig. 4.[1] Its characteristic feature is the Permo-Carboniferous zone which crosses the ridge about midway between and at right angles to the calc-schist formation. The zone or belt is composed of an enormous mass of sphenic diorite which constitutes the Valletta, Ruié, and Gran Nomenon peaks and the intervening Mésoncles and Belleface cols or saddles, and is flanked on either side by considerable banks of sericitic, gneissiform schist and psammitic, carbonaceous sandstone of the greywacke type. The diorite zone, about 4 kilometres in superficial width, extends east into the Cogne Valley and west across the Savaranche Valley to Mont Bioulé on the divide between the latter valley and Val Rhêmes. In the Cogne Valley it was first recognized by Baretti[2] in 1876 and described as sphenic syenite, similar to the syenite of Biella; but Novarese showed it to be essentially dioritic, with 63 per cent of $Si\,O_2$.[3]

The Savaranche and Cogne dark-green diorite varies in structure from compact to granitoid, gneissoid, and schistose, and is normally composed of plagioclase, hornblende, quartz, black mica, aggregations of minute muscovite, and abundant titanite (sphene) crystals up to 1 centimetre in length. Near Colle Mésoncles it exhibits secondary elements, e.g. albite, epidote, actinolite, with unaltered titanite, while on the Val Rhêmes ridge it is essentially fine-grained and massive. The mass thus presents an interesting example of this rock both in its primitive and in its metamorphosed, re-composed, granitoid, and gneissoid form. In upward succession the diorite and gneissiform schist zone is followed by a bank of crystalline limestone, and thence to the summit of Grivola and beyond to Punta Galisia[4] by a constant conformable alternation of calc-schist and pietre verdi banks, the latter up to 500 metres in depth, as part of the belt which encircles the Paradiso gneiss massif. Here again the pietre verdi, predominantly prasinites with strips of serpentinous schist, appear in all their varieties, more especially in the upper Savaranche Valley near Degioz (1,541 m.) immediately west of and below the Grivola

[1] This section is founded on the complete one given by Novarese in "Profilo della Grivola", ibid., p. 497 et seq.

[2] M. Baretti, "Studi Gruppo Gran Paradiso": Mem. Acc. Linceo Torino, 1876, p. 195 et seq.

[3] V. Novarese, "Diorite granitoide e gneissiche Val Savaranche": Boll. R. Com. geol., 1894, p. 275 et seq.

[4] The calc-schists of Grivola and Galisia were assigned to the Mesozoic (Lias-Trias) as the equivalents and continuation of the schistes lustrés by M. Bertrand in his "Etudes dans les Alpes françaises", Bull. Soc. géol. France, vol. xxii, p. 69 et seq., 1894, which marked his return from his temporarily Archæan to his earlier Mesozoic views on that formation. The latter were confirmed by P. Termier in "Les schistes lustrés de la Grivola", Bull. Service Carte géol. France, vol. vii, p. 150 et seq., 1895. The Piémontese calc-schists are, on the whole, more micaceous than the French schistes lustrés, which are more aluminous than the former and to which the designation "série cristallo-phyllienne" is therefore more appropriate. The superposition of calc-schists on Triassic limestone as verified by Franchi and Termier in various localities also occurs in the Roches d'Ambin massif (Petit M. Cenis, upper Susa Valley), where the minute gneiss and mica-schist are overlain by limestone upon which rests calc-schist.

peak, where the pietre verdi rocks contain fine specimens of gastaldite (blue glaucophane) and garnet crystals. The Permo-Carboniferous diorite and gneissiform schist zone of the Savaranche and Cogne Valleys is obviously connected with the similar diorite of Locana in the Orco Valley and of the Ivrea and Val Sesia belt to be dealt with later.

2. *Monte Emilius* (Fig. 1).—A striking contrast to the normal sequence of the crystalline sedimentary and pietre rocks of the Grivola group is presented by Monte Emilius (3,559 m.) and the neighbouring Becca di Nona (3,182 m.), which lie about 12 kilometres south-east of Grivola, and are separated from the latter by the Cogne Valley. Both mountains, with their extremely rugged and craggy flanks, rise straight from the Dora Baltea Valley between Aosta (580 m.) and St. Marcel to a height of 3,000 and 2,600 metres respectively in a horizontal distance of barely six kilometres. The upper parts and summits of both are composed of minute gneiss and eclogitic, garnetiferous mica-schist, while the lower flanks facing the Aosta Valley consist of huge masses of coarse-grained, gneissiform euphodite more or less parallel to the overlying gneiss and mica-schist. On the Monte Emilius flank the encircling calc-schist formation is not in direct evidence, but on Becca di Nona it crops out above Charvenod close to Aosta and again higher up at the Sismonda signal (2,347 m.), where it rests on minute gneiss. In both places the calc-schist dips at a steep angle in opposite directions, while the gneiss and mica-schist of the upper flanks and summits of both mountains are greatly contorted; near St. Marcel, at the lower end of the valley of that name, they descend to the 700 metres contour and then apparently dip below the calc-schist.

The phenomenon of reversed sequence in the Monte Emilius group is the result of an inverted fold in connexion with the great fracture fault which runs along the Aosta Valley to Chatillon and St. Vincent. From here, instead of following the sharp southward bend of the Dora Baltea towards Ivrea, it extends east across the Brusson Valley to Arcezas, where the calc-schist mass at the base of a great gneiss bank affords striking proof of a similar dislocation near the contact with the mica-schist formation of the Ivrea belt.

3. *Monte Rafré* (Fig. 1).—About 12 kilometres east of Monte Emilius, in the calc-schist and pietre verdi area of the Clavalité and Champorcher Valleys previously mentioned, occurs the remarkable sequence of the Monte Rafré (3,146 m.) and Monte Glacier (3,186 m.) group which forms the divide between those two valleys. In this case, a mass of brecciated prasinitic gneiss which crops out on the crest of the divide, overlies a mass of euphodite metamorphosed to prasinites, in apparently reversed sequence. In reality the prasinites, as Stella has shown,[1] are an isolated lenticular wedge intercalated in the brecciated gneiss which lies in the calc-schist formation. The latter, with pietre verdi, extends from the Champorcher Valley to

[1] A. Stella, "Gneiss Monte Emilius e M. Rafré": Boll. Soc. geol. ital., 1906, p. xlvi. E. Mattirolo, "Rilevamento Val Champorcher, Alpi Graje": Boll. R. Com. geol., 1899, p. 3 et seq.

Chatillon and Verrès in the Dora Baltea Valley and thence up the Tournanche and Brusson Valleys, whence it skirts the base of Matterhorn and Monte Rosa.

4. *Mont Mary.*—On the left of the Dora Baltea north of Aosta, and exactly opposite Monte Emilius, rises the Mont Mary (2,875 m.) group, which is the counterpart of the former and exhibits a similar reversed sequence. The calc-schist appears here at the base, and is overlain by Permian schist, upon which rests the cupola of garnetiferous mica-schist. The group, which includes Gran Becca (2,967 m.) and Gran Col (2,864 m.), lies in the zone of the same fracture fault and presents the same phenomenon of an inverted fold as Monte Emilius on the opposite side of the valley. From the Mont Mary group the mica-schist formation extends up Val Pellina and across the crest of the Pennine Alps to Dent Blanche (4,364 m.), north-west of Matterhorn.[1]

The great intrinsic geological interest of the crystalline rock-areas of the Aosta valleys described in the foregoing has in recent years been enhanced by Lugeon and Argand having included them in their grand series of overthrust sheets in that and other parts south of the crest of the Alps.[2] According to their theory, worked out from ingenious geometrical designs, the Gran Paradiso, Grivola, Grand Nomenon, Emilius, Rafré, and Mary groups are not "rooted" or "autochthonous" massifs, but cover-sheets (*nappes de recouvrement*) pushed over from different directions and more or less considerable distances. Investigations instituted by the Italian Geological Survey in 1905,[3] and notably by Novarese in 1909,[4] have, however, conclusively shown that the cupolas of those groups differ stratigraphically and lithologically from the "root" areas whence they are supposed to have been derived, and that, with the exception of the small, isolated massif of Monte Pilonet (2,697 m.) between the Tournanche and Brusson Valleys on the left of the Dora Baltea, where the gneiss cupola completely covers the calc-schist, there is no evidence at all of extensive overthrusts in that part of the Alps.

[1] V. Novarese, "Gneiss Monte Emilius e M. Mary": Boll. Soc. geol. ital., 1912, p. 31. Novarese describes an interesting section of granite, mica-schist, and diorite in a railway cutting between Aosta and Quart, on the left of Dora, below M. Mary.

[2] M. Lugeon & E. Argand, "Grandes Nappes de Recouvrement de la zone du Piémont. Homologies ditto": Comptes rendus Acad. Sciences, Paris, Mai 15 et 29, 1905.

[3] "Relazione": Boll. R. Com. geol., 1906, p. 27.

[4] V. Novarese, "Profilo Grivola": Boll. R. Com. geol., 1909, p. 497 et seq. A. Stella, op. cit., 1912, p. xlvi. "Problema geo-tettonico Ossola e Sempione": Boll. R. Com. geol., 1905, p. 5 et seq. S. Franchi, "Tettonica della Zona del Piemonte": ibid., 1906, p. 123 et seq.

(*To be concluded in our next Number.*)

V.—The Structure and Later Geological History of New Zealand.

By C. A. Cotton, D.Sc., F.G.S., Victoria University College, Wellington, N.Z.

(*Concluded from the June Number, p. 249.*)

SUPPORTED by the great weight of Hutton's authority, his views, with which those of Haast [1] and the early views of Hector [2] were in general agreement, have gained wide acceptance, notwithstanding the opposition of McKay. Marshall, for example, as late as 1911 wrote as follows: "The great elevation [Mesozoic orogenic movement] was succeeded by nearly as great a depression. The majestic mountain ranges were gradually lowered until nothing but a chain of islands showed above sea level. To what a great extent this movement prevailed is seen at Lake Te Anau, where the Oamaru formation, some 3,000 feet thick, rises to the tops of the mountains. At Wakatipu and in the Rangitata valley the Oamaru rocks are found in the recesses of the mountains. In the Trelissick basin and between the masses of the Kaikoura ranges there was deep water. The valleys of the tributaries of the Buller are filled with Oamaru sediments." [3]

Brief reference may here be made to the effects of the Kaikoura movements, though anything like a complete account of the structure and surface forms produced cannot be attempted. In Marlborough the great reverse faults, first noted by McKay, and the huge tilted and compressed blocks from which the Kaikoura ranges have been carved are most impressive.[4] Though less intense the effects in North Canterbury are similar in kind, and a geological map of the district would present the appearance of a mosaic of 'oldermass' and 'covering strata' formations as a result of block faulting, with the preservation of the latter on the lower blocks and their removal by erosion from the higher.

Some remarkable intermontane basins occur as a result of these movements,[5] and the rivers that cross the basins flow out of them by way of deep, perhaps antecedent gorges across the oldermass of the upthrown blocks. The largest of these structural basins, the Waiau-Hurunui Plain, may be mentioned as an example. It is traversed by two rivers of considerable size, the Hurunui and the Waiau, which, curiously enough, make their way out by separate gorges, while the lowest initial gap in the basin rim—as indicated by the structure of the covering strata—is not occupied by a stream at all. A railway enters the basin from the south by way of this gap. The covering strata are in part preserved in the low-lying interior of the

[1] J. von Haast, "On the Geology of the Waipara District": Col. Mus. and Geol. Surv. of N.Z., Rep. Geol. Expl. 1870-1, pp. 5-19, 1871.

[2] J. Hector, "On the Geology of the Manuherikia Valley": Otago Prov. Gov. Gaz., 1862.

[3] P. Marshall, "New Zealand and Adjacent Islands": Handbuch reg. Geol., Bd. vii, Abt. i, p. 40, Heidelberg, 1911.

[4] See C. A. Cotton, "Physiography of the Middle Clarence Valley": Geographical Journal, vol. xlii, pp. 225-46, 1913.

[5] R. Speight, "The Intermontane Basins of Canterbury": Trans. N.Z. Inst., vol. xlvii, pp. 336-53, 1915.

basin and are largely covered by young fluviatile gravel. Numerous other similar but smaller structural basins occur, the covering strata within which are more or less eroded or buried under fluviatile gravel according to their position with respect to local base-levels. It is evident that here, as in Marlborough, faulting has been accompanied, if not actually brought about, by a compressive force, for the covering strata are thrown into folds.

From some of the uplifted blocks the surfaces of which were merely tilted slightly from their former horizontal attitude little below the base of the cover has been removed by erosion, and remnants are thus preserved of the fossil denudation plain which, in places at least, forms the floor of the cover. As an example the western slope of Mt. Grey may be cited. Farther to the south-west the outer ranges of the Southern Alps are composed of irregularly uplifted blocks, upon the tops of which are preserved remnants of a surface of small relief possibly also stripped of a cover.

In the Oamaru district the base of the covering strata is of early Tertiary age, and the beds lie upon a plane-denuded surface of the oldermass. There is less evidence of compressive stress here accompanying the Kaikoura movements, but the beds are thrown into broad folds. The open-water character of the sediments of the cover and the absence of coarse clastics are sufficient to show that the mountains to the west, into the valleys of which the covering strata now penetrate, were not in existence as a high land-mass during the period of deposition. The structure and physiography suggest that the cover had formerly a great westward extension, and this is proved by their occurrence as narrow strips in trough depressions, e.g. in the Shag and Waitaki Valleys. An account of the structure of an in-faulted outlier of the cover at Wharekuri, Waitaki Valley, has recently been given by Marshall.[1] Inland occurrences of the Tertiary rocks are thus easily explicable, and the theory of their deposition in fiord-like arms of the sea, which was advocated for so long by Hutton, must now be regarded as definitely abandoned.

In the Oamaru district large, gently sloping, flat areas of the fossil denudation plain forming the floor of the covering strata have been stripped but not destroyed. Some are seen to dip beneath the outcrops of the cover, as, for instance, south-west of Oamaru, and also in the Waihao basin north of Oamaru, where the presence of such a surface has been noted by Thomson[2] (see Fig. 2). Others occur on the tops of high mountain blocks differentially uplifted and tilted in various directions. Other and larger portions of the high blocks have been maturely dissected, and dissected fault-scarps are of common occurrence.

Farther to the west, in Central Otago, the landscape is a mosaic of blocks the general nature of which has been recognized by McKay[3]

[1] P. Marshall, "Cainozoic Fossils from Oamaru": Trans. N.Z. Inst., vol. xlvii, pp. 380–1, 1915.

[2] J. A. Thomson, "Coal Prospects of the Waimate District, South Canterbury": Eighth Ann. Rep. Geol. Surv., 1914, p. 160.

[3] "On the Origin of the Old Lake-basins of Central Otago": Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl. 1883–4, pp. 76–81, 1884 (p. 80).

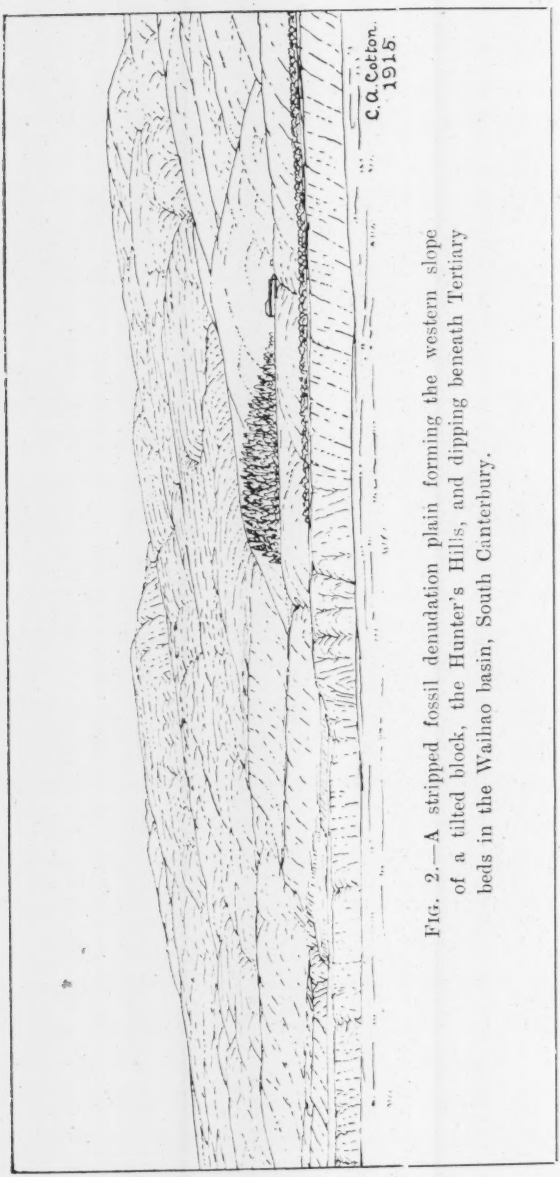


FIG. 2.—A stripped fossil denudation plain forming the western slope of a tilted block, the Hunter's Hills, and dipping beneath Tertiary beds in the Waihao basin, South Canterbury.

and by Park.[1] A group of the lower-lying blocks determines a chain of basins, which have been known in the past as "old lake-basins", though no definite evidence has been adduced that they have been occupied by lakes. The depressions now occupied by large lakes still farther west—e.g. Wakatipu and Te Anau—were probably, as Andrews[2] notes, initially of the same nature; but they have been subsequently profoundly modified by glacial erosion. In Central Otago the covering strata are largely of terrestrial origin and have been preserved over considerable areas on the low-lying blocks in the basins. If, as is probable, there was formerly a continuous or nearly continuous cover on the higher blocks also, it has been removed by erosion, with the exception of a few outliers. The general nature of the Kaikoura deformation is here decipherable, not only from the attitude of the cover in the basins, but also from the configuration of the higher blocks upon which extensive areas of a denudation plain, warped and dislocated by the movements, are preserved. As the plain dips beneath the cover on the flanks of tilted blocks and as it supports outliers of the same beds, it is, at least in great part, a stripped floor. Its virtual continuity with the stripped floor in the Oamaru district indicates with a high degree of probability that it is a part of the same erosion surface, though perhaps not covered until a later date and perhaps never submerged. The majority of the blocks in Central Otago are elongated, trending north-east and south-west, and are tilted towards the north-west, presenting scarp-faces towards the south-east or east.[3] East of the centre of the district a considerable area of the denudation plain forms a more or less horizontal plateau at a height of about 1,000 feet. This has been called the "Central Otago Peneplain" or Barewood Plateau.[4]

In the North Island the absence of a continuation of the main mountain range—the Southern Alps—of the South Island has often been remarked upon, and the statements of Hutton[5] and Suess[6] on the subject are perhaps correctly interpreted as indicating their belief that the north-eastern continuation of the Alpine range has subsided independently. In view, however, of the late date of the movements to which the South Island ranges owe their present height, and in view also of the presence in the North Island opposite those ranges of Tertiary rocks of greater age than the orogenic movements, it would be more correct to say that this portion of the North Island has merely not been uplifted to the same extent as the South Island.

[1] "The Geology of the Area covered by the Alexandra Sheet, Central Otago Division," N.Z. Geol. Surv., Bull. 2, p. 6, 1906; "The Geology of the Cromwell Subdivision, Western Otago," N.Z. Geol. Surv., Bull. 5, 1908.

[2] E. C. Andrews, "Erosion and its Significance": Journ. and Proc. Roy. Soc. N.S.W., vol. xlv, p. 116, 1911.

[3] The structure of this district is well displayed by an excellent geological map by A. McKay in his *Report on the older Auriferous Drifts of Central Otago*, 2nd ed., Wellington, Govt. Printer, 1897 (opp. p. 84).

[4] J. Park, loc. cit., 1906 and 1908; *Geology of New Zealand*, 1910, p. 9.

[5] F. W. Hutton, "Sketch of the Geology of New Zealand": Quart. Journ. Geol. Soc., vol. xli, p. 197, 1885.

[6] E. Suess, *The Face of the Earth* (Eng. trans.), vol. ii, p. 147, Oxford, 1906.

The district around Wellington and that characterized by a continuation of the outcrop of 'oldermass' rocks to the north-eastward —the axis of the island—has not, however, escaped uplift; and a very general sudden steepening of the dip of the younger strata as the oldermass is approached shows that this uplifted block or series of blocks is bounded by monoclinal flexures or faults.[1]

Along the eastern base of the Rimutaka Range there is a well-preserved fault-scarp. Here the structure closely resembles that produced by the Kaikoura movements in the South Island. To the east lies a gently tilted block with its cover much folded; and a broad fault-angle depression—the Wairarapa Valley—exists between the black slope of this block and the steep eastern fault-scarp slope of the Rimutaka Range. The broad tectonic depression extends far to the north-east.[2]

East of the mountain axis the effects of compression are strongly marked, the covering strata being much folded, while westward from the axis they are only very gently tilted. The trend of the features produced by these movements is about north-east, as it is in the neighbouring part of the South Island.

In the northern part of the North Island isolated areas of the oldermass project through the Tertiary formations. To these Suess[3] refers as "isolated fragments of the sunken range", and Marshall[4] expresses agreement with Suess's statement that the "north-west coast in no way represents the actual trend of the mountains".

To the writer the presence of these horst-like masses appears to indicate that the northern portion, in common with the rest of New Zealand, was affected by the Kaikoura movements. From these uplifted areas the covering strata have been removed, and the oldermass has been maturely dissected. In the neighbourhood of the horsts and generally throughout Northern Auckland the Tertiary strata are considerably folded.

Post-Kaikoura Movements.

It is well known that in comparatively recent times some parts of the New Zealand region have been affected by uplift and others by subsidence, while in some parts there is evidence of oscillation. Very brief reference to these movements is all that is possible here. It is important to note, however, that these latest movements generally have the effect, as far as any particular district is concerned, of 'regional' as distinguished from differential movements—of epeirogenic as distinguished from orogenic. In a broad sense, however, these movements really are differential, for the New Zealand region has not moved as a whole. Units of much larger size than the blocks associated with the Kaikoura movements have moved independently.

[1] J. A. Thomson, "Mineral Prospects of the Maharahara District, Hawk's Bay": 8th Ann. Rep. Geol. Surv., Mines Statement, 1915, p. 164.
[2] Thomson, loc. cit., p. 165.
[3] *The Face of the Earth* (Eng. trans.), vol. ii, p. 44, Oxford, 1906.
[4] *New Zealand and Adjacent Islands*, 1911, p. 25.

Tilting of some of the large blocks on a hinge-line may account in some cases for transitions from the features characteristic of uplifted to those of depressed districts, e.g., the northern part of the North Island has been most recently depressed while the southern part has been continuously uplifted, and again in the Marlborough–Nelson district there is a transition from the deeply drowned topography of the Marlborough Sounds through an east-west hinge-line in the vicinity of the town of Nelson to an area farther southward where the last movement has been one of uplift. The depressed Marlborough Sounds district is, however, separated from a very recently uplifted area to the south-east [1] only by the alluvium-filled Wairau Valley, suggesting the presence here of a fault. Faults of late date appear also to have determined the outlines of at least some parts of the New Zealand coast, especially in and about Cook Strait.[2]

From considerations of the latter kind alone one might be tempted to conclude that the latest or post-Kaikoura movements are merely a continuation of the Kaikoura movements; and the formation of the harbour of Port Nicholson, Wellington, by the drowning of a system of valleys resulting from a purely local movement of subsidence [3] appears at first sight to point in the same direction. The Port Nicholson depression is, however, a quite exceptional feature.

If, on the other hand, an appeal for information is made to the physical features of the districts strongly affected by the Kaikoura movements in those parts of Marlborough, Nelson, and Otago that have been uplifted in later times, there is evidence of a long period of rest—during which a cycle of erosion reached an advanced stage—intervening between the two sets of movements. There has, moreover, been no general renewal in later times of movement on the faults of Kaikoura age [4]; and the origins of the earthquakes felt in New Zealand are, with a few exceptions, situated not within the land area but some distance seaward.[5] It would seem that, though the Kaikoura movements may possibly be not quite extinct, they have very generally been succeeded, after a period of rest, by movements of the mysterious purely vertical kind which appear to have no connexion with compression.

Conclusion.

In conclusion the general nature of the relief of the land may be stated in the following brief diagnosis, in which is emphasized the importance of the Kaikoura movements in comparison with the Mesozoic in determining modern features. New Zealand may be described as a concourse of earth-blocks of varying size and shape,

[1] C. A. Cotton, "Preliminary Note on the Uplifted East Coast of Marlborough": Trans. N.Z. Inst., vol. xlvi, pp. 286–94, 1913.

[2] C. A. Cotton, "Fault Coasts in New Zealand": Geographical Review, vol. i, pp. 20–47, 1916.

[3] C. A. Cotton, "Notes on Wellington Physiography": Trans. N.Z. Inst., vol. xliv, pp. 245–65, 1912.

[4] C. A. Cotton, "Physiography of the Middle Clarence Valley": Geographical Journal, vol. xlii, pp. 236–7, 1913.

[5] See G. Hogben, "Notes on some Recent Earthquakes in New Zealand": Trans. N.Z. Inst., vol. xlvi, pp. 301–3, 1914.

in places compressed; the highest blocks lying in the north-east and south-west axis of the land masses, so that the whole structure may be termed a geanticline; the blocks initially consisting of an older mass of generally complex structure much denuded and largely planed, and concealed, over the greater part of the area, by covering strata which had not been disturbed before the 'blocking' took place; the whole, since these movements, has been considerably modified by erosion somewhat complicated by the effects of later movements of uplift and subsidence.

VI.—The Age of the Norseman Limestone, Western Australia.

By Professor J. W. Gregory, D.Sc., F.R.S.

IT is generally agreed that the main plateau of Western Australia has probably stood above sea-level since the earliest geological times, and has perhaps been a land area since the Archæan. Marine deposits lie against its northern, western, and southern borders, but none are known upon the plateau itself; but through the depression of Lake Cowan Kainozoic marine deposits have extended northward into the Dundas Goldfield at Norseman. These marine deposits include a deep lead with sponges which were described by Dr. Hinde (Bull. Geol. Surv. W.A., No. 36, 1910, pp. 7–24, pls. i–iii) and some patches of limestone which occur on the surface around Norseman. They have been described by Mr. A. Gibb Maitland, 1908 ("Recent Advances in the Knowledge of the Geology of West Australia," Rep. Aust. Assoc. Adv. Sci., vol. xi, p. 153, 1906), and by Mr. W. D. Campbell ("The Geology and Mineral Resources of the Norseman District, Dundas Goldfield," Geol. Surv. West Aust., Bull. 21, p. 22, 1906).

These Norseman limestones prove that at the date of their deposition the southern margin of the great plateau of Western Australia stood 1,000 feet below its present level (cf. J. W. Gregory, "The Lake System of Westralia," *Geogr. Journ.*, vol. xliii, pp. 656–64, map, 1914). The date of this submergence is of primary importance in the history of the physiography of southern Western Australia.

The suggestion has been made that the limestone is Pleistocene, and I owe to the kindness of Mr. E. S. Simpson some fossiliferous fragments of the Norseman Limestone which I have examined to see what light they throw on the age of the rocks. The fossils are, however, all in poor preservation. The best preserved of the molluscs have been kindly examined by Mr. A. E. Kitson, who, in spite of his extensive experience with the Victorian Kainozoic, is unable to give any very positive determination. He remarks as follows:—

"I have been over the fossils from the Norseman limestone, but am sorry to say I cannot recognise any of them specifically. They all are too fragmentary even for generic determination. Several appear to be fragments of *Cardita*; others of brachiopods. Two small ones look like young gasteropods (*Natica*?), but they may be adult forms of an identifiable species that I do not know. Two appear to be Turritellas. Speaking from memory of *Turritella*

pagodula, Tate, the ornamentation in these seems to resemble that of Tate's species, which is recorded from Beaumaris, Horsham, and the Gippsland Lakes (Tate and Dennant's Upper Oligocene and Miocene). A lamellibranch seems to have the ornamentation of *Dosinia* (*D. Johnstoni* ? Tate), which ranges from Tate and Dennant's Middle Oligocene to Miocene. I do not like the suggested Pleistocene age for these shells. They may be Pliocene equivalent to the Glenelg R. and Moorabool Viaduct beds of Victoria."

The specimens include several Bryozoa of which the preservation is imperfect, but by the aid of enlarged photographs of some of the specimens a fairly probable identification of five species is possible.

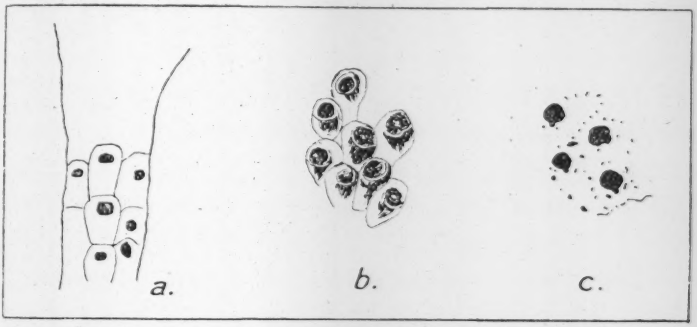


FIG. 1. Zoœcia of three Bryozoa from the Norseman Limestone. × 6 diam.
,, 1*a*. *Cellaria rigida*, McG.
,, 1*b*. *Macropora clarkei* (Ten.-Wds.).
,, 1*c*. *Schizoporella convexa*, McG.

The specimens, however, are so corroded that it is only by piecing together the evidence of several of the zoœcia that sufficient material for identification is obtained. The species that are thus provisionally determinable are as follows :—

Membranipora delicatula (Busk); Miocene, Victoria; Pliocene and Recent.
Cellaria rigida, McG.; Miocene and Recent.
Schizoporella convexa, McG.; Miocene, Victoria.
Macropora clarkei (Ten.-Wds.); Miocene, Victoria.
Schismopora modesta, McG.; Miocene, Victoria.

M. delicatula was founded on Pliocene material, and both it and *Cellaria rigida* still live on the coasts of Australia. The three other Bryozoa, of which the identification is more satisfactory, are typical Victorian Miocene species. *Schizoporella convexa* was founded by McGillivray on material from Muddy Creek, Victoria. All the five species occur in the Victorian Miocenes, and though no positive opinion can be expressed on so short a list of fossils, their evidence is in favour of the Miocene rather than of the Pleistocene age of the Norseman Limestone. The material agree more closely with the Miocene of Victoria than with the Pleistocene. The specimens, however, encourage the hope that more extensive collecting at Norseman would yield sufficient fossils to settle the age of this very significant limestone.

VII.—*Trogontherium* from the Pleistocene of Copford, Essex.

By E. T. Newton, F.R.S., F.G.S., F.Z.S.

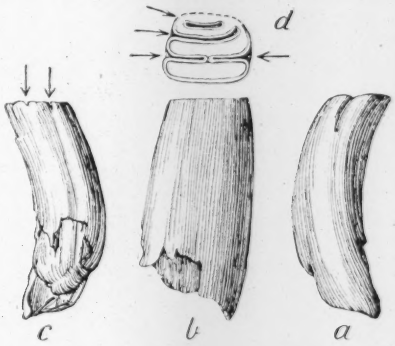
In the year 1852 John Brown, of Stanway, published a paper on the Copford deposits (Q.J.G.S., vol. viii, p. 184), and in this includes a letter from George R. Waterhouse referring to two 'Beaver' teeth and the metacarpal of a Bear. One of these teeth is described and figured, and is said to differ from the beaver in being larger and also in the direction of the enamel folds. This tooth is preserved in the British Museum of Natural History at South Kensington, and I have recently had the opportunity of examining it; but the second tooth I have been unable to discover, concerning which G. R. Waterhouse says it "scarcely differs from that of the European species".

Richard Lydekker (*Catalogue of Fossil Mammalia in British Museum*, pt. i, 1885, p. 221, No. 27985) notices the figured specimen, reproduces the woodcut, and says "it comes nearer to the molars of *Trogontherium*, but does not seem to agree exactly with any specimen available for comparison".

The deposits at Copford, as shown by John Brown, include a comparatively modern deposit, containing many land and freshwater shells, and an underlying blue clay from which remains of "Elephant, Stag, Aurochs, Bear, Beaver" were obtained, as well as some freshwater species of Mollusca. Some geologists seem to have had grave doubts as to the true age of these Copford beds; but at the present time, although there may have been some unfortunate mixing of the shells from beds 2 and 4, there is little room for doubt as to the Pleistocene age of the mammalian remains above-mentioned, nor as to their having been found in the "blue clay" marked in the section as "Brick Earth".

It was just fifty years after the publication of John Brown's paper that the giant beaver, *Trogontherium*, so commonly met with in the Pliocene Forest Bed, was first recognized in the Pleistocene deposits of the Thames Valley (Geol. Mag., 1902, p. 385). Unfortunately when that paper was written I had not studied the Copford 'Beaver', otherwise it might have been included as additional evidence of *Trogontherium* having survived in this country in Pleistocene times. The original figure does not give a good idea of this tooth on account of the direction in which it is viewed, and the careful drawing given on p. 323 may help to remedy this. The enamel of the posterior margin of the worn surface has been chipped away, but its position is indicated in this figure (*d*) by a dotted line; also the basal part has been somewhat broken since the original figure was made. This tooth is an upper premolar 4 of the left side, and agrees very closely with that of *Trogontherium Cuvieri* figured in the Geological Survey Memoir (*Vertebrata of the Forest Bed Series*, 1882, pl. xi, fig. 15, lowest tooth of the figure). I have no doubt as to its reference to *Trogontherium*, and it shows no differences by which it might be separated from *T. Cuvieri*, in which the patterns of the grinding surface of the teeth vary greatly as they are worn down. The rapidity with which the lateral folds of enamel are worn away so as

to leave islands of enamel is one of the chief characters of *Trogontherium* in which it differs from *Castor*, and this feature is strikingly shown in the Copford tooth. Although only a comparatively young tooth, as proved by the narrowness of the grinding surface compared with the remainder of the crown (Figure, *b*), the single inner fold (*a*) extends only 5·5 mm. from the worn surface; while of the three outer folds (*c*) the posterior one is already an



Trogontherium from Copford. Upper premolar 4 from left side. Nat. size. *a*, inner side, showing one fold of enamel; *b*, front surface; *c*, outer side: arrows point to folds; *d*, grinding surface, showing enamel folds and posterior enamel island. The enamel at back of tooth has been broken away, and is here restored by dotted line.

island (*d*) disconnected from the outer wall of enamel, and the other two are nearly in the same condition, the anterior and largest one being only 1 mm. in depth.

	mm.
Greatest length of tooth	28·7
Greatest width of tooth	12·7
Back to front of tooth	9·0
Back to front of worn surface	8·5
Width of worn surface	10·0

I have to thank my friend and colleague, Mr. Clement Reid, for the suggestion that I should examine the Copford 'Beaver' and possibly confirm Richard Lydekker's shrewd perception of its affinity to *Trogontherium*. The results of my examination of the specimen are expressed in this note.

VIII.—Isostasy.

By R. M. Deeley, M.Inst.C.E., F.G.S.

DURING recent years the question of the conditions of stress and strain in the earth's crust has received a very considerable amount of attention. Perhaps one of the most fruitful lines of inquiry has been that which has aimed at determining the connexion between the varying densities of the crustal rocks and the different degrees of relief of the surface of the earth. It soon became apparent that in mountainous or elevated regions the deep-seated rocks were

of less density than those beneath lowlands and seas, and it became clear that the elevated regions were sustained by the buoyancy of the lighter rocks beneath them. The theory that the earth's crust was in isostatic equilibrium thus arose.

Careful measurements have shown that a perfect condition of isostatic equilibrium does not exist. Beneath many mountain ranges the deep-seated rocks are often sufficiently light in character to support mountains of greater elevation than exist above them, whilst in other cases the rocks are not sufficiently dense to support the weights above. In many cases these departures from perfect isostasy are very marked and present considerable theoretical difficulties. Barrell, for instance, concludes that "Isostasy . . . is nearly perfect, or is very imperfect, or even non-existent, according to the size and relief of the area considered".

A very interesting suggestion of Barrell's is that the more or less rigid rocks of the lithosphere are separated from the rigid materials of the nucleus by a region where the rocks are very soft and allow the lithosphere above to float on it. It is taken to extend from a depth of about 200 km. to 400 km. or more.

Barrell suggests that the reason why the condition of isostatic equilibrium is not more perfect than it is, is that the rocks of the lithosphere are so immensely strong that they are able to act as a girder and support the local excess weights in this way. In support of this he calculates that at a depth of 25 km. the rocks are five times as strong as they are at the surface. It seems very doubtful, however, whether the crust could support in this way some of the immense departures from isostatic equilibrium that are known.

Perhaps the difficulty may be explained in another way. In a mountainous area the action of denuding agents keeps reducing the height of the mountains, and the material thus removed is spread over the neighbouring sea-floor. For a condition of isostatic equilibrium to persist such mountains should rise and the sea-floor be depressed. For such a change of level to take place there must be a flow of rock in the region of the asthenosphere from below the sea towards the mountains. Now if the rocks of the asthenosphere were liquid, but very viscous, such a flow could readily take place until isostatic equilibrium was reached. On the other hand, if the rocks were plastic, and very soft, such a flow would not be able to occur until the stresses reached some particular magnitude depending upon the plasticity of the rock. In the case of a liquid the rate of shear is always exactly proportional to the stress producing it; but in the case of a plastic body such flow cannot take place until the stress reaches some particular magnitude depending upon the degree of plasticity of the rock. It thus arises that although the asthenosphere may be of very considerable thickness, the resistance to flow would be very great if the movement had to effect a portion of it, especially if a thousand kilometres or more long. From this it will be seen that perfect isostatic equilibrium is only possible when the asthenosphere is in a liquid condition.

It is probable that in places where the relief is considerable, and the condition of isostatic equilibrium approaches perfection, the

temperature of the asthenosphere is high and the rocks approach very closely the liquid condition.

It is not generally recognized that the conditions of stress necessary to set up flow in a plastic substance are very different from those required to cause flow in a liquid.

REVIEWS.

I.—Ray S. Bassler. Bibliographic Index of American Ordovician and Silurian Fossils. Bull. U.S. National Mus., No. 92. 2 vols. Washington, 1915.

THE term "American" rightly includes the whole of North and South America. Under "Ordovician" and "Silurian" are included all formations that lie between undoubted Cambrian and undoubted Devonian. The "Fossils" comprise Vertebrates, Invertebrates, Plants, and Tracks of doubtful origin. The words "Bibliographic Index" refer to the bulk of the book, also described as a "Bibliographic List of Genera and Species". What a "bibliographic list or index" would really be is somewhat doubtful; what Dr. Bassler has given us is a list of generic names in alphabetical order, with a list of the specific names in alphabetical order under the genera to which they belong. Under each generic name is given the name of the genotype, but it is not stated how this has been determined. Dr. Bassler has not ventured to fix one for *Orthoceras*. The generic and specific names are followed by the main references to literature. Then, for the species, come the horizon and localities (some extra-American), but the type-locality is not distinguished. Lastly, the register numbers are given of any type-material of the species in the U.S. National Museum.

The references to literature are brought down to the close of 1914, except that Schuchert's "Revision of Paleozoic Stelleroidea" (1915) and Springer's "Monograph of Crinoidea Flexibilia" (not yet published) are also indexed. One does not like to quarrel with a good thing; but is there not too much citation of obvious text-books, and indeed of other Indexes, such as S. A. Miller's well-known work? This would be all very well if it did not seem occasionally to lead to the exclusion of far more important references. The long list under *Caryocrinites*, for instance, contains no reference to the classical memoir of L. v. Buch, except by way of the species *C. ornatus*; nor does the discussion of this genus and of the allied *Stribalocystites* in Palæontologia Indica (1906) find mention even under one of the various species. There is a method in this apparently, for under *Petalocrinus*, instead of quoting Bather's elaborate study of the genus published by the Geological Society, Dr. Bassler refers only to the abstract report, and even then, not to the Proceedings of the Society, but to the Geological Magazine; it is only when his new species are indexed that Bather's paper is referred to. To parody Polonius, "Though this be method, yet there's madness in it." The Geological Magazine, here unduly favoured, is on more important occasions ignored: *Lebetodiscus* (Geol. Mag., 1908, p. 550) and

Edrioaster levis (1914, p. 117) are among names we have failed to find. *Brachiocrinus*, J. Hall, is another. Per contra *Botryocrinites*, the name of a series, is quoted as that of a genus. But such slight errors and omissions are almost unavoidable in a first edition.

The "Bibliographic List" is followed by an alphabetical index of trivial names, showing the genera to which each has been attached. There is also an alphabetical list of generic names only, with page references to the same names arranged under a biological classification. This is useful, but it might have saved the reader's time had the main systematic position been indicated by a contraction in the main list, as in Sherborn's *Index Animalium*. The faunal lists which follow must have cost a deal of work, which it is to be hoped will prove warranted by the use made of them. The alphabetic list of American Formation names will certainly be most useful, for there are over 700 used in the book. The correlation of the more important among them is displayed in a set of tables, on the same plan as that adopted in E. O. Ulrich's "Revision of the Palæozoic Systems" (1911).

Geologists and palæontologists will be most grateful to Dr. Bassler for his labours and to the Smithsonian Institution for the publication of this exceedingly valuable aid to research.

II.—Dana's System of Mineralogy.

Third Appendix to the Sixth Edition of Dana's "System of Mineralogy". By William E. Ford. pp. xiii + 87. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd. 1915. Price 6*s*. 6*d*. net.

EVERY working mineralogist has a copy of Dana's great book lying on his table, and would find himself considerably hampered without its aid. Like all books of the kind, as soon as it appears it starts to become out of date. The sixth edition itself was published in 1892, nearly a quarter of a century ago. It is of such a size that frequent revision was difficult, if not impossible; on the other hand, mineralogy, like other branches of science, does not stand still, but has made steady progress. The difficulty was met to some extent by the issue of appendices, of which the first appeared in 1899 and the second in 1909. The present appendix covers the six years from the beginning of 1909 to the end of 1914, but, as the author points out in his prefatory note, the outbreak of war caused some disturbance in the mail services, and it is possible that some of the publications that appeared towards the close of the year were not received and have therefore not been included. This appendix has been entirely prepared by Professor Ford, who had completed the second appendix after ill-health had compelled his colleague, Professor E. S. Dana, to relinquish the task in 1906.

As in the previous appendices, the minerals referred to are arranged in alphabetical order, while a classified list of new names is given in the introductory pages. Reference to the volume is therefore exceedingly simple. Altogether 180 new names are included, but the author regards only one-third of them as well established, the

remainder being evidently varieties of previously known species, or, because of the incompleteness of the investigation, doubtful. The introductory pages contain also a list of the principal literature published during the period in question, a special section being devoted to the literature on the subject of X rays and crystal structure, which constitutes the most striking advance of recent years in the method of investigating the structure of crystals. In order to retain the book within moderate dimensions, the information given under each mineral species is kept as concise as possible, and illustrations are only added in the case of the more interesting species. Under the heading "New Minerals" are given a number of incompletely described minerals which are considered to be new, but have not been named. It was not found practicable to recalculate the angles and other data given, and the particular author's published values were accepted in every instance; errors creep in so easily that an independent check, as was the practice with the Danas, would have been very valuable.

Mineralogists will feel a debt of gratitude to Professor Ford for taking up the task perforce relinquished by the younger Dana.

III.—Origin of the Diamond.

AN original and highly interesting paper on the origin of the diamond, by David Draper and W. H. Goodchild, is to be found in the *Mining Journal* for May, 1916. We have not the space to go into the details of the author's remarks, but must content ourselves with quoting their conclusions:—

1. A kimberlite pipe does not differ essentially from an ordinary volcanic vent.

2. The lava is derived from an infra-granitic zone basaltic in character, eclogite, but the original lava is not necessarily either ultra-basic or highly peridotitic.

3. Minute diamonds may be present invariably as an accessory mineral in the eclogite from which the pipe material is derived, but the evidence on this point is inconclusive.

4. Towards the end of the active period of vulcanicity differentiation of the magma in the vent is brought about by the sinking of early formed crystals, principally olivine and ferro-lime pyroxenes, thus producing an ultra-basic mass in the lower regions of the vent. The ultra-basic character of kimberlite is thus due to magmatic differentiation, and not to a primary derivation from an ultra-basic source.

5. After freezing of the magma in the upper regions of the vent, the molten residuum beneath the solid plug continues to be slowly impregnated with magmatic gases, chiefly water and carbon dioxide, thus hydrating the melt, lowering its viscosity, and prolonging the solidification period, and at the same time effecting extensive serpentinization. The serpentinization is thus due to a solution of carbon dioxide in water under pressure and introduced from below, and is not the result of weathering by downward percolating solutions.

6. During this period a process somewhat analogous to secondary enrichment occurs, resulting in the growth of larger diamonds at the expense of minute crystals.

7. The economic diamond is therefore to be regarded as essentially a secondary mineral grown in situ in the kimberlite matrix.

IV.—The Nitrate Shales of Egypt. By Dr. W. F. Hume, Assoc. R. C. Sci., F.G.S., Director Geological Survey of Egypt.

IN Mémoires de l'Institut Égyptien (1915, vol. viii, pp. 145–69) Dr. W. F. Hume summarizes the work in connexion with the nitrate shales of Egypt. Generally they have yielded on analysis 5 per cent or less of sodium nitrate. The difficulty in their commercial development has been caused by their variability in distribution. They are present at a definite horizon in the geological series, forming part of the uppermost Cretaceous strata (Esna Shales and Ashgrey Clays), and have been traced from Farafra Oasis to West Sinai. Their wide distribution at the same horizon suggests that they represent compounds formed or absorbed at the time of deposition of the shales; on the other hand, the presence of sodium nitrates being only marked near the surface suggests that they are either formed by some means now acting, such as nitrifying organisms working under moist conditions of the soil, or have been drawn to the surface by capillarity.

V.—Geological Survey of New Zealand.

Bulletin No. 17, New Series, of the Geological Survey of New Zealand. By P. C. Morgan and J. A. Bartrum. pp. viii + 210, with 19 plates, 18 figures, 9 maps, and 6 geological sections. Wellington, 1915.

THE authors give an exhaustive account of the geology and mineral resources of the Buller-Mokihinui Subdivision, Westport Division, which district lies on the west coast of the South Island. The mining industries include gold-mining, mainly alluvial, which was at one time very prosperous, but is now almost extinct, coal-mining, and to a small extent rock-quarrying. The supplies of coal, particularly the bituminous variety, in New Zealand are very limited, and will probably approach exhaustion in at the most one hundred and fifty years. The bituminous coal as yet known is contained almost wholly in the Greymouth and Westport Districts. The authors call attention to the loss of coal resulting from the methods of working it. The geological formations consist of two sets separated by a striking unconformity: the one is composed of highly folded greywacke, argillite, hornfels, schist, gneiss, and intrusive acid igneous rocks, which were base-levelled in pre-Tertiary times, and on this peneplain was deposited the second set of strata, consisting of a succession of breccias, conglomerates, grits, sandstones, mudstones, and limestones, in places unconformably capped by Quaternary sands and gravels. The Bulletin is excellently illustrated.

VI.—Eocene Glacial Deposits in South-Western Colorado. By W. W. Atwood. U.S. Geol. Surv. Prof. Paper No. 95 B, 1915, pp. 11–26, with 4 plates.

EVERY addition to the growing list of pre-Pleistocene glaciations is of interest, and Mr. W. W. Atwood gives conclusive evidence for the occurrence of an Eocene Boulder-clay on the plateau of South-Western Colorado. In his study of this deposit he has been aided by a party of advanced students from Chicago University. This Eocene Boulder-clay is situated a mile west of Ridgeway, N.N.W. of the mining field of Ouray, at about 7,800 feet above sea-level. It occurs near Pleistocene glacial deposits. The Eocene Boulder-clay rests upon a wide sheet of Mancos Shale; it consists of a layer, about 100 feet thick, of yellowish till containing a great variety of boulders, including igneous and sedimentary rocks which range from the pre-Cambrian to the Upper Cretaceous. The boulders range up to 5 feet in diameter; they are faceted, and a large proportion are striated. The Boulder-clay is covered by a slate-covered clay containing a few very small pebbles, and this bed is also regarded as a till. Above it rest the Telluride conglomerates and the San Juan tuffs, which are well known from their connexion with the ore deposits of Colorado. The evidence seems conclusive both as to the glacial origin and Eocene age of this deposit, but as Pleistocene glacial beds also occur in the same neighbourhood, and as the Eocene in this district was a period of mountain uplift, this Boulder-clay is an indication of a mountain glaciation and not of any widespread glacial climate.

VII.—Geological Survey of Portugal.

THE yearly volume of the Geological Survey of Portugal contains several interesting papers (Commun. d. Comissão do Serv. Geol. de Portugal, tom. x, 1914). P. Prevost, in writing on the Devonian and Carboniferous of Portugal, demonstrates the presence of all stages of these formations save the Middle Devonian. This paper contains the description of a new species of Goniatite (*Prolecanites algarbiensis*) from the Culm of Aljezur. V. Sousa-Brandão describes at length a universal mineralogical microscope on a new model. The same author also describes "porphyroblastic phyllites" from the Pre-Cambrian of Aveiro. These are divided into staurolite-garnet-phyllites, staurolite-phyllites, and chloritoid-phyllites, which are treated in detail. A supplementary paper describes the optic orientation of the chloritoid in the above-mentioned rock. Economic geology is represented by two papers by P. Choffat, who summarizes the evidence for the occurrence of petroleum in the Mesozoic region of Estremadura, and describes the history and geology of the garnet mines of Suivo which were worked by the Romans. The gems occur in a basaltic breccia. The final paper is a valuable bibliography of the geology of Portugal and its colonies in 1913, by P. Choffat and E. Fleury, which is the eleventh contribution of a similar nature.

G. W. T.

REPORTS AND PROCEEDINGS.

I.—The Royal Society.

June 1, 1916.—Sir J. J. Thomson, O.M., President, in the Chair.

A paper was read by Mr. E. A. N. Arber, Sc.D., "On the Fossil Floras of the Coal Measures of South Staffordshire." (Communicated by Professor McKenny Hughes, F.R.S.)

A flora of fifty-eight species is described from a new horizon in South Staffordshire, the Red Clay series or Old Hill Marls of Transition Coal-measure age. A new genus *Calamophloios* and new species of *Sphenopteris* and *Cardiocarpus* are described, as well as several records new to this horizon.

Ten new records are added to the known flora of the Productive Series (Middle Coal-measures), including new species of *Calamites* and *Lepidostrobus*. A large number of additional records from new localities or horizons are added in respect to fossils already known from these beds.

II.—Geological Society of London.

1. *May* 24, 1916.—Dr. Alfred Harker, F.R.S., President, in the Chair.

Dr. A. Smith Woodward, F.R.S., V.P.G.S., exhibited Devonian fish-remains from Australia and the Antarctic regions, and discussed our present knowledge of the Devonian fish fauna of the southern hemisphere. So far as is known, there are no strange elements in this fauna, and the remains discovered closely resemble those met with in the Northern Hemisphere. Even the rocks are very similar to those containing the corresponding fossils in the Northern Hemisphere. There is, as yet, no satisfactory evidence of the basal Devonian fish fauna such as occurs in the Downtonian of England and Scotland; but both Lower and Upper Devonian forms occur in Victoria and New South Wales (Australia). A Coccostean related to *Phlyctænaspis* from Gippsland (Victoria), and another related to *Macropetalichthys* from Goodra Vale (New South Wales), may be regarded as Lower or Middle Devonian; typical plates of *Bothriolepis* from the Harvey Range (New South Wales) indicate an Upper Devonian fauna. The fish-remains obtained by the *Discovery* Expedition in Granite Harbour (Antarctica) comprise *Bothriolepis*, another Ostracoderm related to *Byssacanthus*, Acanthodian scales, Selachian dermal tubercles, a Coccostean, scales of Osteolepidæ, and scales of a very small Palæoniscid. They must be regarded as Upper Devonian.

Dr. Woodward expressed his indebtedness to the Government Geologist of New South Wales for the loan of the Australian specimens exhibited.

Mr. R. Bullen Newton exhibited some so-called Orbitoidal Limestones from Dutch New Guinea, the microscopical structures of which were shown by lantern illustrations. The specimens were collected by Dr. A. F. R. Wollaston during his expedition to that country in 1912–13, on the snow-line of Mount Carstensz at a height of 14,200 feet, this mountain forming the highest elevation of New

Guinea, with an altitude of about 16,000 feet. The foraminiferal organisms determined in this material included five species of *Lepidocyclina* (*sumatrensis*, *martini*, *neodispansa*, *murrayana*, and cf. *insulæ-natalis*), *Amphistegina*, *Carpenteria*, *Cycloclypeus* (cf. *orbitoideus*), etc.; the marine alga or nullipore, *Lithothamnium*, was, also, largely represented. This assemblage compares favourably with that which characterizes rocks of similar age in other Pacific regions, such as Christmas Island (Indian Ocean), Formosa, the Philippines, Borneo, Celebes, Sumatra, Nias, Timor, Australia, besides indicating a Miocene origin. It was pointed out that the genus *Orbitoides* of A. d'Orbigny had been restricted by Schlumberger (relying on the researches of Gümbel, Verbeek, and others) to species having rhomboidal equatorial chambers and belonging only to Cretaceous times; species furnished with rectangular chambers, and recognized as *Orthophragmina* of Munier-Chalmas, were limited to the Eocene and Oligocene formations; while Gümbel's genus *Lepidocyclina*, with rounded or hexagonal chambers, included species of Miocene and later age. As the result of a study of species from Borneo and the Philippines, Professor Douvillé had proposed to divide *Lepidocyclina* into two sections—*Eulepidina* and *Nephrolepidina*: the first including forms of generally large size, recognized as Aquitanian; the second for those of small dimensions, regarded as Burdigalian—these geological divisions representing the oldest stages of the Miocene system. This distinction, however, was not applicable to the New Guinea limestones nor to corresponding rocks from Christmas Island, as both large and small species occurred in association; it was therefore suggested that the age of the New Guinea material might be referable to the later part of the Aquitanian. Several writers have already written on rather similar limestones from various parts of New Guinea, although we are indebted to Dr. K. Martin for the first announcement in connexion therewith: he reported the discovery in 1881 of Lepidocycline organisms from rocks found in the north and south-western end of the country (Geelvink Bay, islands of Kei, Aru, etc.), which he attributed to the older Miocene. The same author also referred to the occurrence of similar organisms in Mount Wilhelmina, obtained by Dr. Lorentz, beneath which the *Alveolina* Limestone was identified, proving the existence of Eocene rocks.

The *Cycloclypeus* remains, which are of frequent occurrence in the present material, bear a strong resemblance to Professor Douvillé's new genus and species from the Miocene of Borneo, known as *Spiroclypeus orbitoideus*. This genus was stated to have all the characters of *Cycloclypeus*, but differing from it in the possession of superficial chamberlets in the shelly layers of the central region. Recent investigations, carried out by the speaker, had proved the presence of this character (hitherto unrecognized) in modern forms of *Cycloclypeus* from Funafuti; hence the retention of *Spiroclypeus* now appeared to be unnecessary. A full report on this New Guinea collection by the speaker had been lately published, entitled "Notes on some Organic Limestones, etc., collected by the Wollaston Expedition in Dutch New Guinea"—forming No. 20 of a series of reports, and it was to be included in vol. ii of those reports.

2. *June* 7, 1916.—Dr. Alfred Harker, F.R.S., President, in the Chair.

Dr. F. L. Kitchin, M.A., F.G.S., exhibited a representative set of Mesozoic fossils obtained from deep borings and pit-sinkings in Kent. The specimens were selected from the collections of the Geological Survey, by permission of the Director. The life of the successive zones present in the various sections was illustrated by the arrangement of the specimens in sequence, the series comprising a time-range from the Lower Lias up to the top of the Lower Greensand. The section revealed in the Brabourne boring is remarkable for the range of formations found there in superposition, and may be regarded as the type-section for the study of the hidden Mesozoic succession in Kent. Specimens were exhibited from that locality and from the shafts at Dover, but these were supplemented by materials obtained more recently from various borings situated east of a line drawn from Folkestone to Canterbury.

The speaker described the principal characters of the faunas as developed in this area, and made incidental references to the nature and distribution of some of the associated rock-types. At some horizons the molluscan assemblage assumes a particular aspect by reason of the preponderance of species fitted for life amidst the special conditions of deposition. On the other hand, there are evolutionary phases which recur repeatedly with considerable uniformity, and seem to arise independently of immediate surrounding conditions. Such are illustrated by the degenerative changes shown to occur in many Ammonites, and by some of the forms repeatedly assumed by the members of separate series among Mesozoic oysters.

The evidence of Ammonites, so important for the purpose of zonal determination, is frequently forthcoming at these localities in Kent, even in borings of narrow diameter, but it is often necessary to rely entirely upon the aid afforded by the more abundant bivalves. Many of these, although belonging to undescribed species, are found to have a limited vertical range, and by their distribution throughout this area, as well as farther afield, prove of much service in these correlation studies. Specimens of many undescribed species have come to light, as well as others which are known from their occurrence in Continental localities, though not previously recorded in this country.

A small series of Jurassic Cephalopoda from Kachpur (Russia), collected by the late G. F. Harris, F.G.S., at the time when the International Geological Congress met at Petrograd (1897), was exhibited by James Francis, F.G.S.

III.—Zoological Society of London.

1. *May* 9, 1916.—Dr. S. F. Harmer, M.A., F.R.S., Vice-President, in the Chair.

Miss Dorothea M. A. Bate contributed a paper dealing with a collection of vertebrate remains from the Har Dalam Cavern, Malta. Birds are most numerously represented therein, and include some bones of an Anserine bird showing a reduction in its powers of flight. It is believed to be a hitherto undescribed species, and is referred to the genus *Cygnus*. A list is given of all the species of

vertebrates recorded from the Pleistocene cave and fissure deposits of the island.

2. *May* 23, 1916.—Dr. Henry Woodward, F.R.S., Vice-President, in the Chair.

The Rev. H. N. Hutchinson, M.A., F.Z.S., exhibited the plaster cast of a model, four feet long, which he had constructed of the Dinosaur, *Diplodocus carnegiei*.

Lieut. R. Broom, M.D., C.M.Z.S., R.A.M.C., read a paper on the structure of the skull in *Chrysochloris*.

Two stages in the development of the skull have been studied. The earlier is that of a newly born *Chrysochloris hottentota*, whose skull has been cut into microscopic sections and reconstructed, and a somewhat later stage of *Chrysochloris asiatica*, whose skull has been prepared for the study of the membrane-bones. The following are the most interesting features discovered:—

External to the exoccipitals on each side is a large membrane-bone which partly covers the petrosal or periotic. This is believed to be the homologue of the bone which occurs in Therapsid and most primitive reptiles, and usually referred to as the tabular. The sections prove that it is no part of the auditory capsule.

Along the inner side of the prearticular or "goniale"—the little membrane-bone which supports the underside of the upper end of Meckel's cartilage—is a second membrane-bone, which, it is believed, has not been previously recognized in the mammal skull. This may be the homologue of the reptilian surangular.

Under the back part of the nasal capsule, and situated between the capsule above and the alisphenoid and pterygoid below, is a large membrane-bone of doubtful significance. It is probably the homologue of the "postero-lateral vomer" of Parker.

The skull is held to be in some respects highly specialized and in others degenerate, although also retaining a number of very primitive characters.

Dr. C. W. Andrews, F.R.S., F.Z.S., described an incomplete sternum of a gigantic carinate bird from the (?) Eocene of Nigeria. Comparison with the sterna of several groups of birds leads to the conclusion that this specimen, though differing considerably from the sternum of any living member of the group, belonged to a very large representative of the Tubinares. It has about twice the linear dimensions of the sternum of an Albatross, of which the spread of wing (in the flesh) was 10 ft. 8 in. It is proposed to refer this species to a new genus *Gigantornis*, the specific name being *G. eaglesomei* after its discoverer.

Dr. A. Smith Woodward, F.R.S., V.P.Z.S., read a paper on a mammalian mandibular ramus from an Upper Cretaceous formation in Alberta, Canada. The specimen represented an opossum-like marsupial, and he referred it to a new species of *Cimolestes* named *C. cutleri* in honour of its discoverer, Mr. William E. Cutler. The close dental series behind the canine measured 30 mm. in length, and the molars differed from those of the two known species of the genus in their relatively less elevated trigonid. The fourth premolar was

a large, tumid, laterally compressed cone, with one well-separated posterior cusp.

IV.—Geologists' Association, London.

June 2, 1916.—George Barrow, Esq., F.G.S., President, in the Chair.

The following paper was read: "The Petrology of the North Sea Drift and Suffolk Brick-earth." By Percy G. H. Boswell, D.Sc., F.G.S., A.R.C.S.

1. The varied facies of the North Sea Drift and Suffolk Brick-earths. Mechanical analyses; graphical representation of results; economic values; comparison with other British deposits.

2. Petrography. Detrital residues and comparisons with residues from other glacial beds.

The paper was a sequel to that published by the Geological Association in 1913, dealing with the field evidence which served to distinguish the North Sea Drift (Lower Glacial) from the Brick-earth of Suffolk (Upper Glacial).

The three facies of the North Sea Drift, (*a*) the Cromer Till, etc., of the coast sections, (*b*) the Marly Drift of the Western area, and (*c*) the inland Norwich Brick-earth, were briefly considered. Mechanical analyses were given of the deposits, and expressed graphically by means of curves. The Lower and Upper Glacial deposits were shown to conform to very different types, pointing to different modes of genesis. They could easily be distinguished from one another by grade composition.

Although small variations in mineral composition occurred, the Upper and Lower Glacial Brick-earths did not each possess a distinctive and differing mineral assemblage. As would be expected from the varied sources of their constituent materials, the glacial deposits generally yielded an exceedingly rich and beautiful assemblage consisting of over forty mineral species, many of which were derived directly from the breaking up of fresh igneous rocks. The most abundant detrital minerals included garnets, epidotes, hornblendes, and pyroxenes (soda-bearing varieties included), hypersthene, micas, staurolite, kyanite, andalusite, apatite, and others.

A lecture was also delivered (illustrated by lantern views) entitled "Notes on Erosion Phenomena in Egypt", by Miss Mary S. Johnston, F.R.G.S.

Amongst other phenomena of erosion the lecture illustrated the decomposed igneous rocks at the Second Cataract, and the pot-holes and shade-weathering in the granite of the First Cataract. The variation in the constituents of the Nubian Sandstone, the rivers of blown sand on the west of the Nile, and the famous quarries of Gebel Silsileh were described. Reference was made to interesting geological features of the Theban mountains, notably the Eocene chert concretions, and the dry river-valleys and gravels. The significance of certain sites from which numerous worked flints have been collected were also considered and illustrated by views and specimens. The action of the sun, wind, and water upon the Mokattam limestones was referred to in connexion with the formation of Wadi Hof and the production of the etched surface of the Sphinx.

Fine specimens of split and eroded cherts from Oligocene gravels were shown.

V.—Geological Society, Glasgow.

At a meeting of the Geological Society of Glasgow on May 11, 1916, Mr. Macnair exhibited a series of specimens got from the ancient bed of the Clyde in the course of digging the foundations of the new Dalmarnock Power Station. The specimens consisted of hazel-nuts, twigs and timber, and the epidermis of pearl mussels. The pearl mussels had lost all trace of their calcareous shells through the action of percolating water, and only the chitinous epidermis remained, resembling dead leaves in brittleness and form. He pointed out that the occurrence of such relics had been recorded about half a century ago in proximity to the present course of the Clyde, and there could be no doubt that they came from the same bed which also contained human relics in the shape of dug-out canoes.

Professor J. W. Gregory read a paper on "The Auld Wives' Lifts: a Pseudo-Megalithic Tor". He described the position of the well-known stones and referred to the traditional explanation of their origin, which ascribes them to a trial of strength between three witches of the district. For long the stones have been regarded as an example of a cromlech erected by the race which has dotted the country with megalithic structures. Careful examination, however, has shown that the group is purely the result of natural processes of denudation isolating a portion of the gritty sandstone of the district which had been dismembered and the fragments thrown into their present attitude by slipping along joints and bedding planes. It was shown that this could be proved by the fact of the existence of the lines of fracture of prominences corresponding with hollows on the opposite block.

Mr. Ludovic McL. Mann pointed out that although the erection of the blocks could not be ascribed to man and the structure differed in some respects from the typical cromlech, there could be no doubt that it had been adopted by the early inhabitants of the district. He believed that the upper surface of the capstone had been levelled by the prehistoric process of 'knapping' and had then been sculptured, the traces being quite evident to the trained eye. Other evidence also showed that the district had been one of special interest to the early inhabitants and was now of importance to the archæologist.

VI.—Mineralogical Society.

June 20.—Dr. A. E. H. Tutton, F.R.S., Past-President, in the Chair.

Dr. J. W. Evans: The Relations between different Laws of Twinning giving the same Twin-crystal. If the untwinned crystal has no symmetry, different twin-laws give different results. In the presence of a centre of symmetry an axis of rotation-twinning is an axis of reflection-twinning. An axis of rotation-twinning lying in a plane of symmetry has at right angles to it in the same plane an axis of reflection-twinning. If the normal to a plane of symmetry be an axis of rotation-twinning, or if a line of symmetry (axis of even symmetry) be an axis of reflection-twinning, the same result may be